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American Landscape: How Suburban Lawns Impact Surface Runoff Volume

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Abstract:

A staple in our suburban society, lawns occupy an important role in urban and suburban hydrology. This thesis investigates the potential impact of lawn quality on the total runoff volume for a given area after storm events. The study focuses on residential lots with areas between ⅛ - and 3 acres, identified using state tax parcel data. Using the TR-55 Curve number methods the mean curve numbers and total runoff volumes were calculated for each section and scenario parameter. Hydrologic Soil Groups and land cover types were used in the determination of initial curve numbers and the TR-55 curve number method was modified to apply to residential lawns. The study was split into three sections: Sections 1 and 2 focuses on the lawns within the Chittenden County portion of the Winooski River Basin in the State of Vermont. Section 1 models how the change of lawn conditions impacts total runoff volume for the areas. Section 2 focuses on changing only certain percentages of lawns to fit certain lawn quality criteria. In Section 3 the mean curve number change and total runoff volume for theoretical residential subdivisions and individual homes were analyzed. It was found that as the lawn qualities increased the total runoff volume from storm events decreased. The larger the residential lot size the greater the total runoff volume, and the greater the percent change when lawns were improved. This decrease was more pronounced in smaller-sized storm events. Although improving lawn quality was seen to have a smaller effect on the Winooski River Basin, improved lawn quality can have a significant impact on total runoff volume for subdivisions and individual homes.

I. Introduction:

Natural History of Lawns in the United States

A symbol of wealth and domesticity, American lawns are the quintessential depiction of the "American Dream". Lawns occupy the spaces between urban and rural life. While urban living is thought of as an abundance of concrete and the absence of trees, rural life is just the opposite. What lies in the middle of these two extremes is suburbia: people living in a large single-family home placed in the middle of a pristinely maintained green lawn. Cheaper than living in the city but more expensive than the country, suburban neighborhoods epitomize the American Dream.

Derived from the word *Laude*, a middle English term defining an open space in or between forests, the definition and depiction of lawns globally remain relatively consistent. Not just an aesthetically pleasing part of the homeowning experience, lawns serve a multitude of ecosystem services to people. Lawns provide numerous regulating services such as reduction of soil erosion, the improvement of water retention, and aiding in reducing the heat island effect. Lawns also provide cultural services by creating recreational space as well as visual aesthetics. From people's yards to golf courses and playing fields, lawns are a symbol of American pride.

Taking up 1.9% of the United States' total land use, turfgrass is categorized as the largest irrigated crop, three times larger than corn, having a total area of around 163,800 km^2 larger than the state of Georgia (Milesi, 2005). Not only do lawns take up physical space, but they require economic and time investments from each homeowner. In 2018 the U.S Bureau of Labor noted that Americans on average spend 70 hours a year working on their lawns (BLS, 2019). Consuming 695 to 900 liters of water per person per day, irrigated lawns are allocated a large proportion of urban and suburban water (Milesi, 2005). To maintain a green and abundant lawn, a plethora of fertilizers and pesticides are used. Although these chemicals are intended to help lawns thrive, they are mutilating the earth below the grass as well as the waterways. It is estimated that 70 million pounds of pesticides are used in the maintenance of lawns each year (NRDC 2016). It is known that lawn care operators use more herbicides per acre than commercial agriculture farmers use on their fields and half of the surveyed homeowners said they did not fully read the instructions on their lawn pesticide containers (Steinburg, 2006). Weeds are not desired, only uniform blades of green grass. Lawnmowers and weed whackers are commonly used to maintain the look of uniform blades of grass. Nearly 200 million gallons of gas are used every year to maintain these lawns (NRDC, 2017). In addition, it is estimated that while refueling these mowers Americans spill nearly 17 million gallons of gas into the ecosystem (Steinberg, 2006). The superfluous application of fertilizers and pesticides results in many of these phosphates and nitrates runoff the lawns into the waterways around them. This increase in nutrients for the surrounding water basins can lead to eutrophication, dead zones, water contamination, and biodiversity loss.

The shift from rural to urban and then to suburban is a defining factor of the 20th and 21st century in the United States. The United States Census Bureau considers an urban area a location where more the 50,000 people reside (Cornish, 2019). By this definition locations typically thought of as suburban are classified as urban under the census. In 2020 approximately 272.91 million people were living in urban areas, about 82% of U.S. citizens. In a study done by the American Housing Survey, 52% of U.S households describe their neighborhoods as suburban (Mitchell, 2018). Pew Research Center demographic studies show, show that 55% of the U.S population is currently living in suburban areas (Mitchell, 2018). As more people are moving from the cities and rural areas to the suburban ones the house sizes and lot sizes are changing. From 1992 to 2019, the average lot size of a newly built detached single-family home has decreased from 10,000 square feet to 8,200 square feet (Cornish, 2019). The average residential lot size in the United States is 12,632 square feet which are a little over one-fourth acre (0.28 acres). The average home to lawn ratio is about 1:6 with an average of 10,871 square feet of lawn and an average footprint of a home being around 1,761 square feet. This ratio varies dramatically throughout the fifty states. The State of Vermont has the highest ratio with an average home to lawn ratio of about 1:40 (73,979 average square feet of lawn to an average 1,815 square feet of home). The lowest ratio is in the State of Nevada with a home to lawn ratio of 1:3. New England (Vermont, New Hampshire, Maine, Massachusetts, Rhode Island, and Connecticut) has an average ratio of home to the lawn of 1:20 (Mitchell, 2018).

Overarching Research Question

- How does the lawn quality condition impact the total runoff volume during storm events?
- Do improved lawn conditions have different flood mitigation potential at different spatial scales?
- Based on Hydrologic Soil Conditions and lawn conditions how can stormwater infrastructure be impacted or changed?

Using Models for Predicting Runoff Volumes

Environmental Models are attempts to simulate different realistic scenarios. Even though these complex models have been modified and studied for a year, they are not an accurate portrayal. Models are best used to show the potential change in something, for this thesis the change in runoff volume when the lawn conditions change. The model used is the Technical Release 55: Urban Hydrology for Small Watersheds (TR-55). For models to be applied to multiple scenarios, many assumptions need to be made. It is in these assumptions that cause models, specifically the TR-55 model to not produce accurate volumes. This model can be used to find the actual total runoff volume during different storm events, though it is not accurate in comparison to in situ data. The TR-55 Model is best used to investigate how different scenarios increase or decrease surface runoff volume. I intend to use the TR-55 model to assess the impact of the change in lawn qualities on runoff volume for different spatial scales.

Lawn Characteristics and Management

Types of Grass

The type of grasses found in people's backyard or other commercial lawns varies with climate. Most typical "American Dream" style lawns in the United States are populated by cool seasons grasses like Kentucky Bluegrass and certain species of fescues. These grasses prefer cooler climates typically found in the Northern half of the United States. Though these lawns exist in hotter climates, they are composed of different grass mixes or require more watering. Most home lawns are made up of a mixture of grass species, selected for different ecological requirements, with the most abundant grass type used is Kentucky bluegrass (*Poa pratensis).* Native to Europe and Asia, Kentucky bluegrass and was brought over to the United States in the early 18th century for estate lawns (Penn State Extension, 1996). The grass was selected for its velvety smooth texture and cold hardiness. Despite its appealing aesthetics, Kentucky bluegrass is a higher maintenance lawn grass, requiring watering, fertilizing, regular mowing, and other soil amendments. Yet, its texture and appearance still make it the dominant choice in turfgrass lawns. Kentucky Bluegrass grass needs about 1 inch and up to 2 inches of rain or water weekly, making it a more water-dependent grass. Kentucky bluegrass typically requires more fertilizer than other tall fescue grasses and is mowed to 2 or 2 1/2 in height (Penn State Extension, 1996).

Planting a diversity of native species on lawns instead of monoculture Kentucky Bluegrass is more beneficial to soil health, human health, and biodiversity.

Management Types

Turfgrass is known for its high evaporation rates with crop coefficients around 1, meaning they have a high evapotranspiration rate. Additionally, the high stem count imposes friction on overland flow, thus delaying and reducing storm runoff that is necessary for mitigating flood risk. The hydrological benefits of a lawn depend, however, on its quality. Poorly maintained lawns may not have the same ability to mitigate stormwater. With turfgrass's apparent lack of biodiversity, poor soil quality, and increased soil compaction rates, lawn management may be a contributor to urban flooding.

Depending on the lawn's climate, lawn management styles can vary. For this study, I looked at the State of Vermont's climate and what management styles result in a biodiverse and ecologically successful lawn. An ecologically successful lawn is comprised of a large diversity of native plants. Lawns with more complex and diverse root systems provided by established native plants absorb more water and reduce the odds of runoff, erosion, and flood events (Zuazo, 2008).

Urban and Suburban Flooding in Vermont

History and Future of Vermont Flooding

Urban flooding is a complex and understudied hazard. Flooding events occur not only during extreme weather events but in areas with high percentages of impervious surfaces flood events can occur during typical rainstorms. The Federal Emergency Management Agency (FEMA) defines urban flooding as "the inundation of property in a built environment, particularly in more densely populated areas, caused by rain falling on increased amounts of impervious surfaces and overwhelming the capacity of drainage systems" (FEMA, n.d). Lawns play two roles in urban flooding: first as mitigation and second as a catalyst. High compaction rates in lawns like golf courses and playing fields contribute to the effect that the total potential impervious surfaces have on runoff. With climate change altering rain patterns throughout the world, many cities in the global north have experienced significantly higher rainfall events with smaller recurrence intervals.

Strom Water Infrastructure

Rain gardens and retention ponds are typical stormwater infrastructure that helps mitigate the total surface runoff that ends up in neighboring water bodies. As more people move to urban centers the total percent impervious surface increases. With more impervious surfaces the need for stormwater and green infrastructure also increases as the water infiltration decreases. The creation of these stormwater infrastructures helps urban and suburban centers prepare for flooding events. This thesis analyzes the runoff impact when lawn conditions are changed at three different spatial scales. Looking at three different scales allows for a comparison of different stormwater infrastructures and how they might be impacted by a change in lawn condition. The three scales modeled in this thesis are the greater Winooski River basin, theoretical housing plots, and theoretical subdivisions. If the improvement of lawn conditions reduces the total runoff, then smaller stormwater infrastructures must be built. Does the change in lawn condition quality have an impact on the necessary stormwater infrastructure?

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II. Research Location:

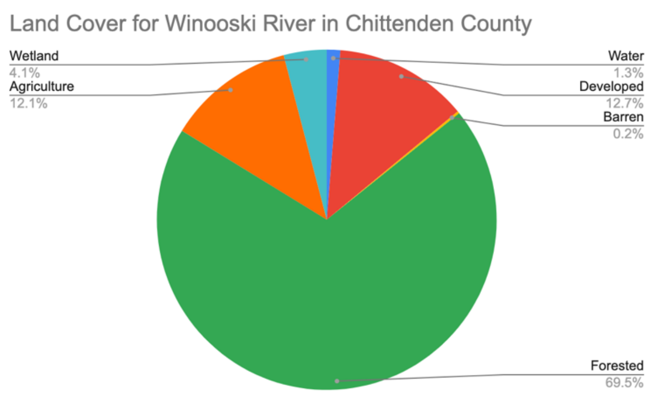
The Winooski River Basin

The Winooski River Basin is part of the larger Lake Champlain Drainage Basin located in Northern Vermont. It is the eighth categorized basin in the State of Vermont and is the most populated river basin. Named by the Abenaki people for the wild onions that used to line the riverbed, the Winooski River basin is a predominately forested watershed. The Winooski River flows over 90 miles from Cabot to Lake Champlain. It travels through four counties including all of Washington County, the majority of Chittenden County, and then small parts of Lamoille and Orange Counties. The basin has seven major tributaries: Little River, North Branch, Kingsbury Branch, Huntington River, Mad River, Dog River, and Stevens Branch. For this case, study the lower Winooski tributaries and parts of the Huntington River basin are studied. There are 15 hydroelectric dams along the Winooski River in addition to the 75 other dams (Winooski Watershed, 2011). Originally and currently used for farming irrigation, the Winooski River Basin land use has changed over the years. The river basin was at one time home to over 40,000 dairy cows and over 30 dairy processing plants. Although these numbers have been reduced to around 13,000 dairy cows and five milk processing plants (Winooski Watershed, 2011). As Vermont farms decreased in both size and number, the once cultivated land was turned into housing subdivisions (Winooski Watershed, 2011). Since 1982 land classified as agriculture in the Winooski River Basin decreased from 16% to 10% while residential developed land increased from 6 to 8% (Winooski Watershed, 2011). Of the 8% developed land in the Winooski River Basin 70 to 80% is residential all mostly found in Chittenden County (Winooski Watershed, 2011)

Hazards to the Winooski River

The State of Vermont Contributes 630 MT/Year of phosphorus into Lake Champlain (LCBP, 2020). It is known that 90% of the phosphorus is due to surface runoff events (LCBP, 2020). Urban and developed areas contribute 18% of the total phosphorus loading in Lake Champlain (LCBP, 2020). Among these developed areas are residential lawns. The Winooski River Basin, specifically Chittenden County, has a higher population density than any other Vermont Basin, thus residential lawns play a critical role in fully understanding the hazards facing the basin.

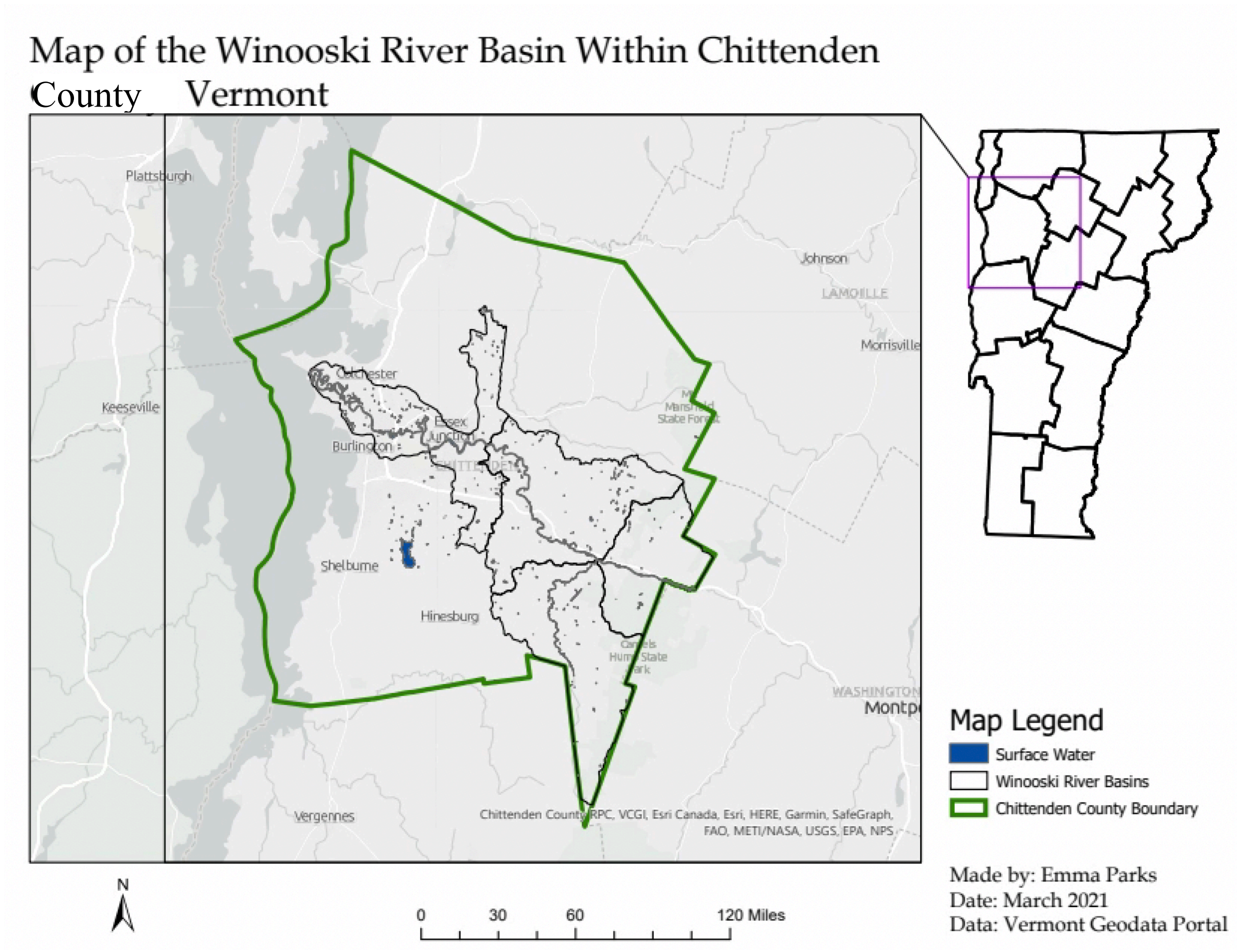
Figure 1: Pie Chart showing the distribution of Land Cover types for the Winooski River Basin in Chittenden County, Vermont



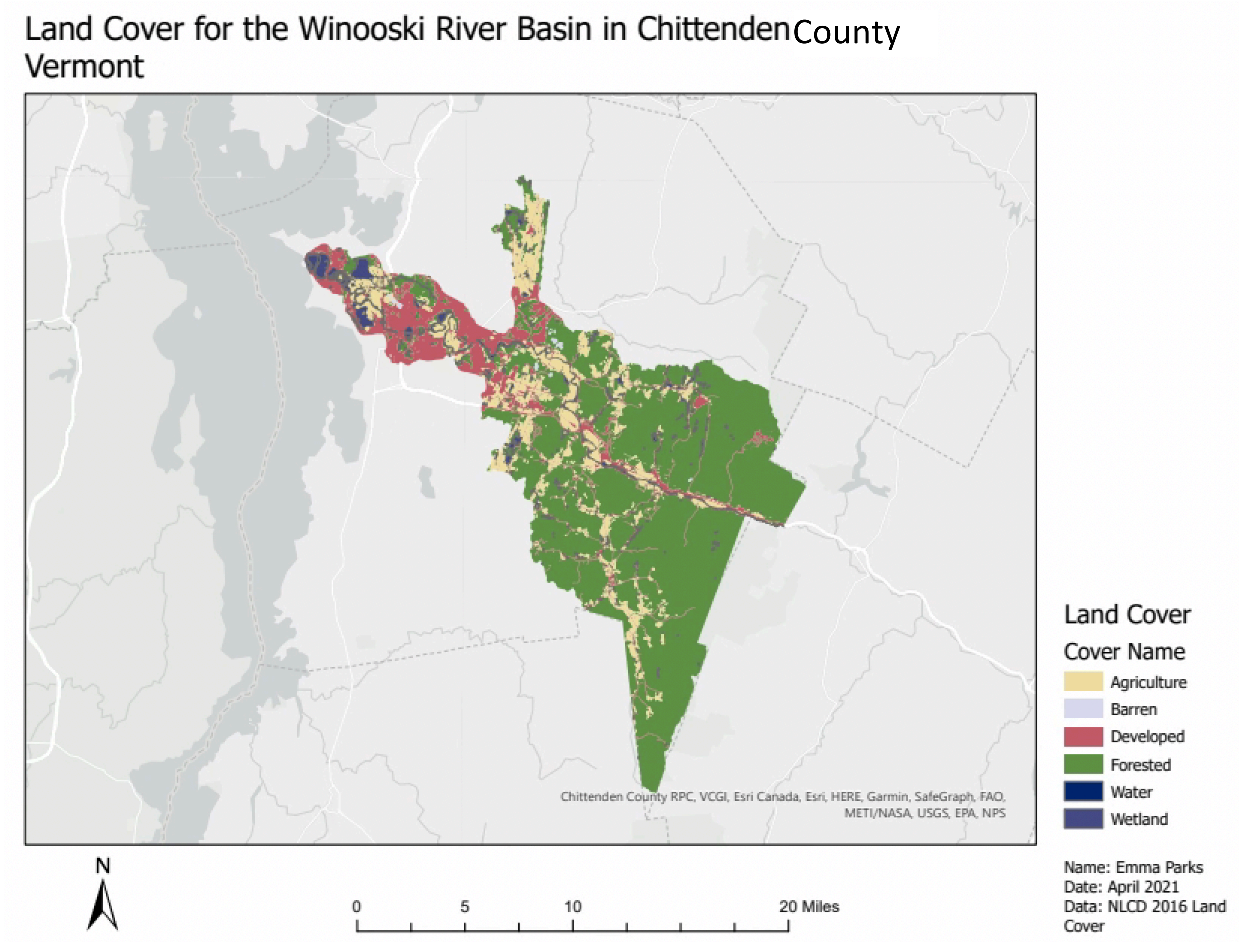
These excess nutrients lead to eutrophication, declining flora, and fauna, along with decreased water quality. Phosphorus and nutrient load are one of ten stressors that the Winooski River currently faces. The other nine stressors are channel erosion, encroachment, land erosion, acidity, flow alteration, invasive species, toxins, pathogens, and thermal stress (*TBP*, 2018).

Chittenden County

In this case study, the part of the Winooski River Basin located within Chittenden County was analyzed. The part of the Winooski River Basin that is located within Chittenden County totals 123,289 acres. For the greater River basin, the breakdown of land use distribution is 77% forested, 8% developed, and 10% agriculture. When analyzing the portion of the basin in Chittenden County, only 69.5% of the basin is forested while 12.7% of the land is developed. This portion of the Winooski River Basin has the largest cultivated and developed land use percentage than any other county or tributary within Vermont (*TBP*, 2018). Chittenden County is made up of 18 towns, though only 14 towns have residences within the Winooski River Basin.



Map 2.1: ArcMap showing the greater Chittenden County outline. Within the county, the outline is the Winooski River Basin boundaries (black). The surface water is shown in blue. Reference map showing the location within the State of Vermont.



Map 2.2: ArcMap showing the Land Cover distribution of the Winooski River Basin in Chittenden County Vermont.

Citation:

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III. Methodology

Overview of Challenges

While the Winooski watershed cannot be regarded as a very large river system, it is one of the most important contributors of water to Lake Champlain. It is a complex watershed that encompasses many different land covers. In Chittenden County, the area of focus for this study, there are large tracts of woodland in the eastern part of the watershed and high-density residential closer to the lake in the larger Burlington conurbation. Furthermore, the residential lot sizes differ greatly, ranging from much greater than 3 acres in the more rural areas to 1/8 acre lots in the urban environment.

The complexity of the land cover in this portion of the watershed required the use of several GIS geospatial databases to garner the baseline information. It was challenging that each town has a different way of classifying residential land use, the land cover where one would expect lawns to be. Additionally, with the assumption that very large lots consist of most of the forest or pasture, I hypothesized that changes in lawn quality on very large lots would not make much difference to the runoff. For this reason, I chose to apply the methodology described below only to lots that were less than 3 acres in size.

The broader hypothesis that lawn quality could impact storm runoff was evaluated based on the Curve Number method for calculating runoff volume that places weight on land and vegetation quality. For example, an open space with a poor quality of soil and vegetation generates more runoff than one with better quality. Because, without a field survey, the initial quality of the lawns was not known. Therefore, certain assumptions about baseline lawn quality were made before defining scenarios of lawn quality change. It was determined that the following methodology is not applicable for large residential plots. The open space condition is based on the percent of impervious area on the plot. Houses, driveways, and other structures are assumed to exist on every residential plot, contributing to a consistent impervious area. Plots of 1/8 to ¼ acreage are given the "Poor" condition because the percentage of impervious area is highest, no matter the conditions of the rest of the plot. Properties of 1/3-1/2 acre are assigned a rating of "Fair" and residential plots of 1 or more acres, presumably with the lowest percentage of impervious surface, are assigned a baseline condition of "Good".

To remediate this issue theoretical housing plots and subdivisions were created and studied in Section 3.

Defining and Locating Lawns in the Watershed

The average American lawn is too small to detect on the land cover data currently available. For the State of Vermont, specifically Chittenden County the highest resolution is 30 m This means that the total lawn area and condition had to be determined using already established impervious surface to land cover ratios. To see if changing the lawn quality condition had an impact on the total runoff from residential properties the study was broken down into four parts. The first two parts are dedicated to defining the baseline or status of lawns and large-scale, Chittenden County stormwater scenarios. In the first two parts, all the residential lawns are manipulated and changed, based on different condition parameters defined below. These Chittenden wide analyses of changes in lawn conditions focus on potential large-scale flooding. The second two parts are theoretical scenarios of runoff generated from individual plots and housing subdivisions. The theoretical scenarios on lawn conditions of single plots and residential subdivisions try to evaluate the local impact of storms under different lawn conditions. These scenarios relate to the design of green infrastructures such as stormwater retention basins and rain gardens.

Curve Numbers and TR-55 Modeling

How the Curve Number Derived

To estimate the total runoff generated by 24-hour storms the Curve Number method was used. Curve numbers (CN) depend on the watershed soil and land cover conditions. The Curve Number method is described in the Technical Release (TR)-55 Model (USDA, 1986) in which several variables interact to predict runoff from storms. For this study, the method was simplified to depend on two land properties: hydrologic soil group and land cover type.

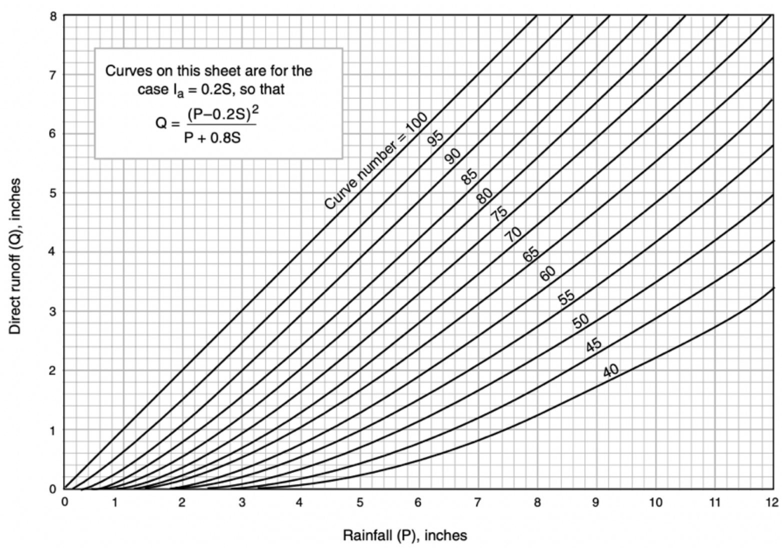


Figure 3.2: Graph Showing the relationship between curve number, rainfall, and runoff. Graph from the USDA TR-55 Curve Number Method Report

The TR-55 is an empirically based method of estimating runoff and peak discharges for small watersheds. The TR-55 model is predominantly used for agricultural, urban, and urbanizing watersheds as the Curve Number method is less effective in forested areas. However, some adjustments have been made to make it suitable for these applications too.

The equations used in the TR-55 model are shown below. Essential to these is the estimation of a Curve Number. The relationship between curve number, rainfall, and runoff volume is shown in the nomograph in Figure 3.1.

Equations and Constants

Q= Runoff(in)

S= Potential maximum retention after runoff begins

CN=Curve Number

I_a= Initial Abstraction

P=Precipitation(in)

$I_a = 0.025S$

$S = \frac{1000}{CN} - 10$

$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Substituting I_a into the equation gives

$Q = \frac{(P - 0.025S)^2}{(P + 0.975S)}$

And S can be expressed in terms of CN, a known quantity for a given land-use scenario.

$$Q = \frac{(P - 0.025\left(\frac{1000}{CN} - 10\right))^2}{(P - 0.975\left(\frac{1000}{CN} - 10\right))}$$

In this equation, P is measured as the storm volume in inches of a 24-hour storm. The initial abstraction gives the initial fraction of rainfall that occurs before runoff is generated. S is the potential maximum storage or retention of water after runoff begins. To estimate the total runoff of the lawns for a given scenario the following equation was used.

$Volume\ of\ Runoff = Q * Total\ Area$

Initial abstraction depends on both surface roughness and the canopy structure of vegetation. It is essentially the amount of water held back from runoff before runoff begins. Water can be stored in depressions but also on leaves of vegetation. The greater the leaf area the more initial abstraction. The original Initial abstraction number for agricultural applications or I_a was set to a value of 0.2. Recent studies have shown that this abstraction value cannot be applied to all types of catchments (Krajewskim, 2020). A study conducted in Poland saw that when looking at urbanized river catchment the true abstraction number averages 0.025 instead of the traditional 0.2 (Krajewski, 2020). This indicates the greater ease with which water can runoff urban surfaces than from agricultural surfaces. The Winooski River Basin within Chittenden County is more accurately described as an urban catchment so the I_a value for runoff and discharge calculations was changed to 0.025.

Cover Descriptions

I used ArcGIS to evaluate land cover in the Winooski River. This system has immense capabilities for geospatial analysis. It is also generally used by the geospatial research community and there are many environments and demographic geodatabases available. The following databases in Table 1 were used in this study:

Table 1: Table showing the Geodatabases used to complete this study and a brief description of the databases

Geodatabase	**Notes**
https://www.mrlc.gov/data/legends/national-land-cover-database-2016-nlcd2016-legend	National Land Cover Database
https://geodata.vermont.gov/datasets/vt-data-statewide-standardized-parcel-data-parcel-polygons?geometry=-80.352%2C42.478%2C-64.532%2C45.249	From Vermont Geodatabase. Statewide tax parcel polygons
https://geodata.vermont.gov/datasets/vt-subwatershed-boundaries-huc12?geometry=-80.337%2C42.732%2C-64.517%2C45.492	Vermont Subbasin HUC 12
Natural Resource Conservation Service County Soil Survey Data	Made by the U.S. Department of Agriculture, Natural Resources Conservation Service
https://geodata.vermont.gov/datasets/vt-usgs-digital-line-graph-surface-waters-area-polygons?geometry=-80.398%2C42.458%2C-64.578%2C45.231	Surface water polygons in Vermont
https://geodata.vermont.gov/datasets/vt-data-county-boundaries?geometry=-80.352%2C42.478%2C-64.532%2C45.249	County Boundaries for the State of Vermont

Lawn and Plot Information

To identify and isolate the residential properties in the Winooski River basin, the State of Vermont tax parcel geodatabase was used. This database contains all properties within the state, along with descriptions for each plot. All the properties designated as residential and that was within a 1/8-to-3-acre plot were selected and merged into a new geodatabase for use in this project. I assumed that parcels greater than 3 acres had either the high quality of lawn based on its size or based on the demographics of the Winooski River Basin, which was forested. I also wanted to focus on smaller more urban residential plots.

Hydrologic Soil Group

Hydrologic Soil Groups are classified by the Natural Resource Conservation Service. There are four Hydrologic Soil Groups: A, B, C, D. Typically the absorbency and the infiltration decrease as you move from A to D.

Group A: Low runoff potential due to its absorbency and a high infiltration rate. Group A soils keep this high infiltration rate even when wet. Typically sand, sandy loam, or loamy sand. Group A has a high rate of water transmission.

Group B: Soil that is silt loam or loam. Moderate infiltration rates when already wetted and mainly consisted of well-drained soils with a somewhat coarse texture.

Group C: Soils that are sandy clay loam with a low infiltration rate when wet. Soils that create a barrier for downward water movement.

Group D: Highest runoff potential and very low infiltration rates. Soils that are clay loam, silty clay loam, sandy clay, silty clay, or clay. Also, soils have a high-water table and a high swelling potential. These soils also have a clay layer near the surface to further impede water retention.

To determine the Hydrologic Soil Group for each of the residential plots ArcGIS was used. I was able to assign each residential parcel a Hydrologic Soil group in the following process

1. Hydrologic Soil Groups were overlaid with polygons representing the residential land parcel

2. Assigned every A group soil polygon were assigned the value 1, every B group polygon the number 2, Every C group polygon a 3, and every D group polygon a 4.

A=1, B=2, C=3, D=4

3. Using the statistic calculator, I analyzed which soil value (1,2,3, or 4) showed up most frequently in each residential parcel.
4. Once the average number (based on the soil hydrologic group) was identified for each parcel then a Hydrologic Soil Group could be assigned to each parcel according to the following chart:

Table 3.2: Table showing the Hydrologic Soil Groups and the average value assigned to them to determine the residential parcel Hydrologic Soil Group

Hydrologic Group Average Score	Hydrologic Soil Group
1-1.5	A
1.5-2	B
2.5-3.5	C
3.5-4	D

Open Space Conditions and Composite Curve Numbers

Before the open space conditions can be established the initial curve number has to be determined for the residential plots. The process for determining the curve numbers is as follows:

1. Establish that the lot is residential through the processes shown above.
2. Each residential parcel was given a cover name based on the acreage of the lot: 1/8 acre, ¼ acre, 1/3 acre, ½ acre, 1 acre, or 2 Acre

   Note: If the residential lot were less than 0.1 acre or larger than 3 acres, they are removed from the database
3. Using Table 3.2, the already established Hydrologic Soil Grouping, and cover name, each residential plot can be given a curve number

   Example: Using ArcGIS one can select all residential parcels that have the cover name "1/4 acre" and the Hydrologic Soil Group B and determine that they have a curve number value of 75

Table 3.3: Table from the USDA TR-55 Curve Number Model report showing the Curve numbers for; Open Space, Impervious Areas, and Residential districts based on the Hydrologic Soil Groups

Cover description: Cover type and hydrologic condition	Average percent impervious area 2/	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

To determine the lawn quality without surveying or mapping the 'Open Space Condition' shown in Table 3.3 was used. Open space condition is used when referring to lawns, parks, golf courses, cemeteries, or other similar cover types. As shown in Table 3.3, the 'Open Space Condition' is defined based on the grass cover percentage. This percentage is representative of the density of the grass or the percentage of barren space between the blades of grass. As the conditions of the open space areas increase the curve number decreases within the hydrologic soil group (Table 3.3). Areas that are designated as "Good" have better soil retention and overall quality. It is assumed that residential lots that are smaller than one acre are fairly classified as "Poor" or "Fair" because there is not enough area or opportunity to optimize the quality of the lawn. The following table shows the appropriate lawn quality designation in coordination with the lot size:

Table 3.4: Table showing the designation of the lawn quality condition based on the plot sizes.

Plots	Lawn Condition
1/8-1/4 Acre	Poor
¼-1/2 Acre	Fair
½- 3 Acre	Good

Visual Examples of the Lawn Quality Distinctions

Figure 3.3: Image showing the Lawn Quality Condition of "Poor"

Figure 3.3 shows an example of the “Poor” lawn quality condition where there is less than 50% grass cover. In “Poor” lawn conditions there are often large barren spaces and spread-out thin grass patches.

Figure 3.4 shows an example of the “Fair” lawn quality condition where there is more than 50% grass cover but less than 75%. In “Fair” lawn conditions there are often not large barren spaces but instead grass throughout, but it is spread out thin patches.

Figure 3.4: Image showing the Lawn Quality Condition “Fair”

Figure 3.5: Image showing the Lawn Quality Condition “Good”

Figure 3.5 shows an example of the “Good” lawn quality condition where there is more than 75% grass cover. In “Good” lawn conditions there are no barren spaces, and the grass is thick, and the soil is not visible.

The process in determining the Open Space Condition and composite curve number is as follows:

1. Determine the Hydrologic Soil Group and Cover name for the individual parcel.
2. Based on Table 3.3 each over the name has an average percent impervious
    a. Example: A ¼ acre residential plot has an average impervious surface of 38%
3. It is assumed that if 38% of the plot is impervious (house and driveway) then the remain 62% is grass or lawn
    a. Percent Impervious for each Cover Name type is provided in Table 3.3
        i. Percent Impervious= P_{imp}
    b. Percent Lawn = 100 - P_{imp}
        i. Percent Lawn = P_{lawn}
4. The Open Space Condition is determined Based on Table 3.4
5. Then based on the Hydrologic Soil Condition, a curve number can be established for the grass
    a. Example: A ¼ acre plot on B soil has an Open Space condition curve number of 69.

Since the open space condition curve number is the only representative of the grass portion of the residential plot a composite curve number, CNC, must be calculated.

$$CNC = \left(P_{imp} * 98\right) + \left(P_{lawn} * OSC\right)$$

Example Calculation: The residential plot is ¼ acre with a hydrologic soil group of B's and the lawn's open space condition is "fair".

Percent Impervious surface: 38%

Curve number for impervious surfaces: 98 (98 is the Curve number for paved parking lots, roofs, driveways, etc.)

Percent Lawn: 62%

Curve Number from Open Space Condition: 69

$$Composite\ CN\ for\ the\ lot = (0.38 * 98) + (0.62 * 69)$$

$$Composite\ CN = 80.02$$

Using this formula, the composite curve number was determined for all the residential parcels between the size of 1/8 acre to 3 acres. For this study, the lawn conditions were changed from "Poor" to "Fair" or any other combination based on the variables set in each part studied. This change in lawn condition is represented by the change in the open space condition curve number which affects the composite curve number for the individual residential plot. To calculate the runoff value for all the residential plots observed in the Winooski River Basin, the mean curve number, CN_m had to be calculated. Since each residential plot is a different size, the following formula was used to accurately represent the mean curve number.

Mean Curve Number, CN_m

CN_i = composite Curve number of parcel i A_i= Parcel Area of parcel i

$$Mean\ Curve\ Number = \frac{\sum CN_i * A_i}{\sum A_i} = \frac{(CN1*A1)+(CN2*A2)+(CN3+A3)\ldots}{total\ area}$$

Storm Volumes and Return Periods for the State of Vermont

For this study, six different storm events were used to calculate the impact of lawn condition, plot size, and Hydrologic Soil Group on storm runoff volume: two storms that are within normal rain expectance for The State of Vermont and four storms that are considered as extreme weather events. The storm events chosen were based on the United States Department of Agriculture storm weather monitoring services (USDA, 1986). The following table indicates the range of storm events and associated rainfall:

Table 3.5: Table showing the storm events used in this study and their recurrence intervals based on the USDA report

Storm Event	Storm Recurrence Interval
0.5 inch	Light Shower
1.0 inch	Light Storm
2.5 inches	2 years

3.75 inches	10-25 year
4.5 inches	50-100 year
7 inches	Hurricane Irene

Lawn Condition Changes

Section 1.1: "All In" Condition Change

To examine how the mean CN and runoff volume change when changing lawn conditions, I constructed seven scenarios:

1. Changing all the current lawn conditions to a "Poor" open space condition (Equivalent to having a poor lawn)
2. Changing all the lawns from the current condition to "Fair" open space condition. (Equivalent to having a fair lawn)
3. Changing all the lawns from the current condition to "Good" open space conditions. (Equivalent to having a good lawn)

Section 1.2: "Interval" Condition

4. All the currently "Poor" lawns change to "Good" conditions while every other lawn remains the same.
5. Referred to as "One Step", this is where all the "Poor" lawns change to "Fair" quality, all the "Fair" change to "Good" and all the "Good" remain the same.
6. All lawns that are currently "Fair" change to "Good"
7. All lawns that are currently "Poor" change to "Fair"

For each of these seven scenarios, the mean curve number is recalculated and the runoff values for each of the six storms are recalculated. The results from these calculations can be analyzed to observe the potential impact that changes to lawn quality might have on the runoff.

Section 2.1: *Changing Open Space Conditions for Certain Percentage of Lawns*

For the second part of this study, there are three scenarios. Since it is not practical to assume that every lawn would be able to improve its condition, a certain percent of lawns was changed to see if there was a change in mean curve number and total runoff. The three scenarios were each split into two parts.

Scenario 2.1: Randomly selecting 25% of the lawns no matter their current condition.

Part A: All parcels with the initial condition “Fair” or “Poor” changed to “Good”. Parcels with the initial condition “Good” remain unchanged.

Part B: All parcels with the initial condition of “Fair” changed to “Good”. All parcels with the initial condition of “Poor” changed to “Fair”.

Scenario 2.2: Randomly selecting 25% of the remaining lawns and adding them to the 25% in Scenario 1, affecting a total of 50% of the parcels

Part A: All parcels with the initial condition “Fair” or “Poor” changed to “Good”. Parcels with the initial condition “Good” remain unchanged.

Part B: All parcels with the initial condition of “Fair” changed to “Good”. All parcels with the initial condition of “Poor” changed to “Fair”.

Scenario 2.3: Randomly selecting 25% of the remaining lawns and adding them to the 50% in Scenario 2, affecting a total of 75% of the parcels

Part A: All parcels with the initial condition “Fair” or “Poor” changed to “Good”. Parcels with the initial condition “Good” remain unchanged.

Part B: All parcels with the initial condition of “Fair” changed to “Good”. All parcels with the initial condition of “Poor” changed to “Fair”.

The curve numbers from both Part A and Part B for all three scenarios are calculated and the projected runoff for each storm event is generated.

Section 2.1: *Comparing the Changes based on Lot Size*

The next step was to see if the percentage of parcels for which the condition was changed had a greater or lesser impact on potential runoff, by parcel size. The lawns chosen for the 25%, 50%, and 75% remained the same, however, the mean curve numbers and the runoff values were now not based on the entire basin but focused on certain lot sizes. The residential parcels are broken up into acreage categories: 1/8 acre, ¼ acre, 1/3 acre, ½ acre, 1 acre, and 2 acres. To calculate a new mean curve number and then the subsequent runoff values the following steps were followed:

1. Separate the residential parcels into their “acreage cover names”: 1/8 acre, ¼ acre, 1/3 acre, ½ acre, 1 acre, and 2 acres
2. Calculate the total area for each acreage category
3. With the known area then the Mean Curve Number equation can be used for each category and each scenario already established in Part 2

Part 2.2: Comparing Changes based on Soil Hydraulic Group

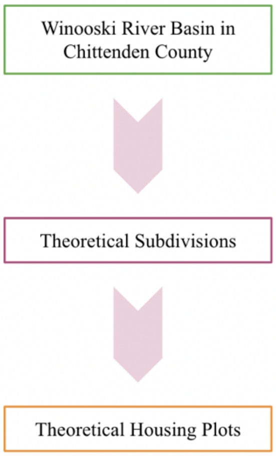
Section 2 evaluated the potential difference between the four hydrologic soil groups after the percent changes for lawn quality were established in Part 2. The residential parcels were split into their Hydrologic Soil Group: A, B, C, or D. To calculate a new mean curve number and then the subsequent runoff values the following steps were followed:

1. Separate the residential parcels into their Hydrologic Soil Groups: A, B, C, D
2. Calculate the total area for each Hydrologic Soil Group
3. With the known area then the Mean Curve Number equation can be used for each Hydrologic Soil Group and each scenario already established in Part 2
4. Once the mean curve number is known, the total runoff volume can be calculated

Section 3: Theoretical Scenarios

Due to the limitations of the methodologies stated above, theoretical housing plots and subdivisions were estimated. For the Winooski River Basin calculations are limited because the current geospatial technologies are unable to estimate grass coverage on areas smaller than 0.25 acres (30m resolution). This means that I had to base my calculations on the assumption that all the residential parcels had the same impervious area for each plot size category and then subsequently the resulting open space condition.

Section 4.1: Theoretical Development Conditions



In some cases, when evaluating a river basin when one applies a change no matter how large scale, the results do not yield a noticeable change. From this point of view, it would make sense to also evaluate the effect at the next scale down which would be a subdivision. For this theoretical observation, two subdivisions with different hydrologic soil groups were evaluated. These theoretical subdivisions allow for a broad application. The subdivisions used for this section represent the average new-build United States Subdivision.

This theoretical model addressed the question: How does changing the lawn conditions of all the lawns in a subdivision impact the runoff volume and mean curve number? For this experiment two subdivisions differed only in the soil hydrologic group:

Subdivision 1:

- Hydrologic Soil Group A
- 30 homes
- ½ acre plots each

Subdivision 2:

- Hydrologic Soil Group B
- 30 homes
- ½ acre plots each

For each of the subdivisions, the total runoff for each of the six storm events considered in this study was calculated for when all the lawns of all the homes were in three conditions were: Good, Fair, or Poor.

Section 4.2: Theoretical Housing Plot Conditions

Can the management of individual lawns affect the size of rain gardens that the house owner may want to install? The second theoretical scenario is at the housing plot level. This is one scale down from the subdivision. The data calculated in Parts 1 and 2 were unique to the Winooski River Basin and would not be as applicable to river basins with different soil types or different lot sizes. To see how the curve numbers and potential runoff change based on house size and soil type, theoretical scenarios were calculated. There are five theoretical houses each with different sized plots: 1/8 acre, ¼ acre, 1/3 acre, ½ acre, and 1 acre. Each house was modeled for either a "Good", "Fair", "Poor" lawn on either A, B, C, or D soil hydrologic group. For each house, there was a total of 12 possible combinations of lawn quality type and soil type. Once all those combinations were calculated for the five houses an analysis was performed focusing on how the change of lawn conditions affect the mean curve number. For example, when looking at a 1/8-acre house on C soil, one can calculate the change in the curve number if the lawn condition changed from "Poor" to "Fair". There are 60 possible lawn condition changes when looking at the 12 possible combinations associated with lawns. The many scenarios' possibilities are shown in Figure 2. Once the CN_m was calculated then the total runoff volumes were determined.

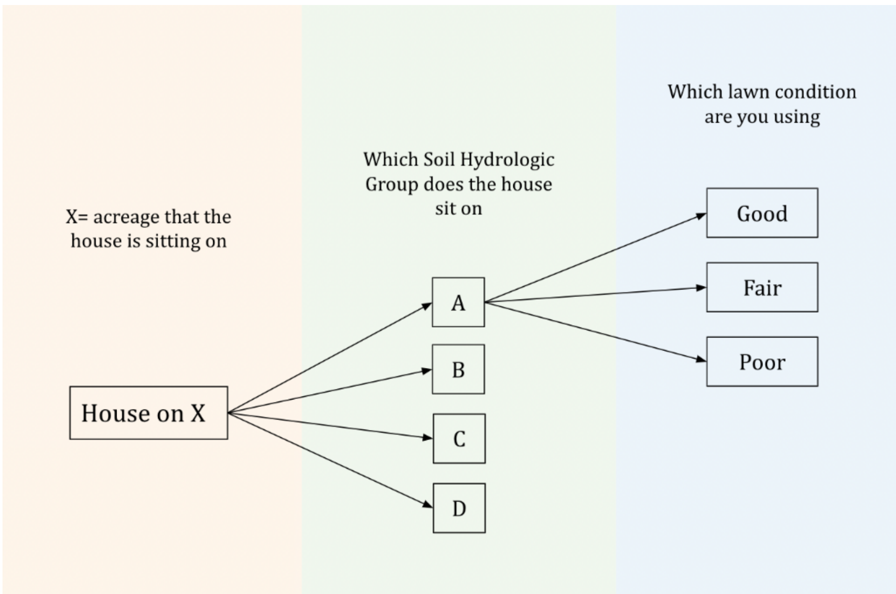


Figure 3.5: Figure showing the different possible combination of lawns for the theoretical housing scenario

Citations

Krajewski, Adam, et al. "Variability of the Initial Abstraction Ratio in an Urban and an Agroforested Catchment." *Water*, vol. 12, no. 2, 2020, p. 415., doi:10.3390/w12020415.

USDA. *Urban Hydrology for Small Watersheds*. Engineering Division, Soil Conservation Service, U.S. Dept. of Agriculture, 1986.

IV. Results

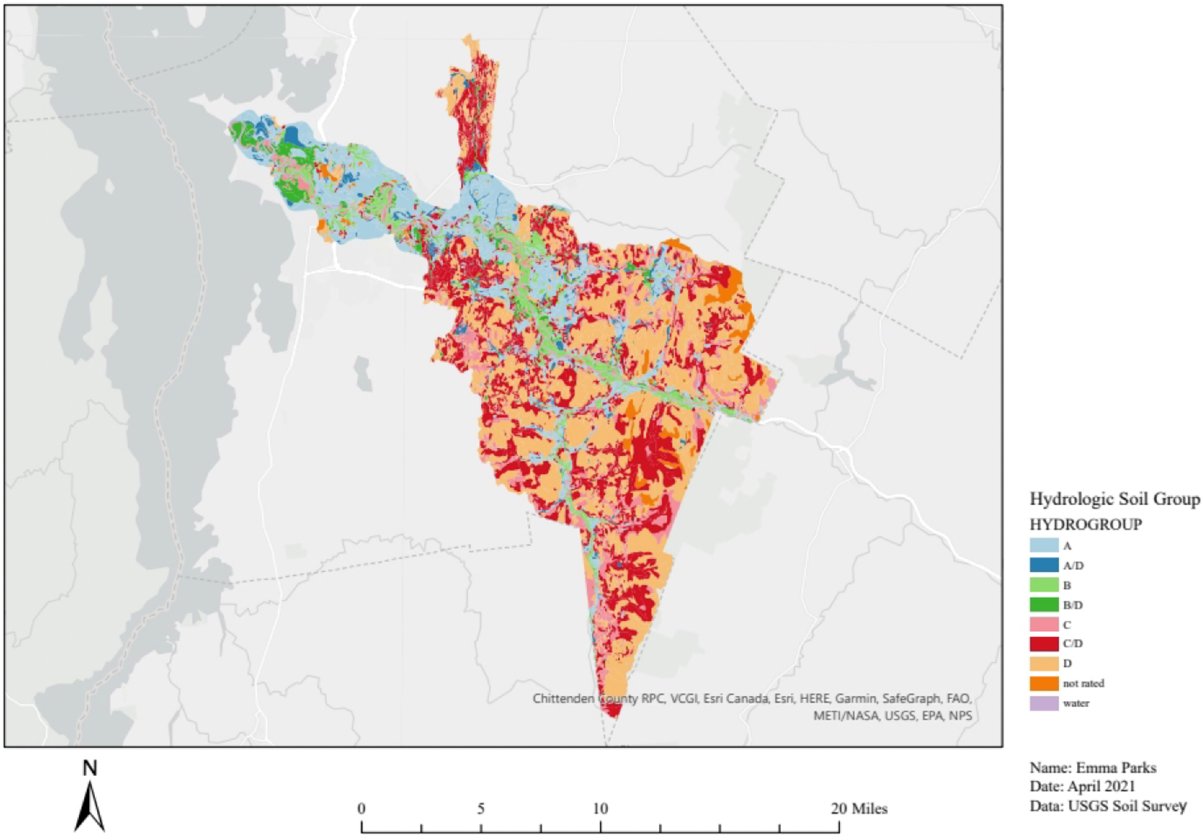
Identifying Residential Lots

Table 4.5: Table showing the towns in the Winooski River Basin in Chittenden County, the residential lot distribution and total area per town.

Winooski River Basin		
Town	**Count**	**Area (Acre)**
Bolton	169	166.74
Buels Gore	4	4.48
Burlington	1524	379.42
Colchester	1326	881.21
Essex	3038	1463.98
Hinesburg	12	21.11
Huntington	350	427.75
Jericho	160	230.83
Richmond	765	927.43
S. Burlington	576	175.72
Starksboro	1	0.45
Westford	15	24.17
Williston	1400	1049.43
Winooski	1239	294.17
Total Area	**10569**	**6047.59**

Table 4.1 shows the contribution of each town in the Chittenden County portion of the Winooski River Basin. There are a total of 10,569 lots with plot sizes between 1/8 and 3 acres. The total area occupied by these lots is 6,047.59 acres. There are 14 towns in this study area, some of which are entirely within the basin while others had only a few residential properties that fit the criteria. For example, the entire town of Essex was located within the river basin while only some parts of South Burlington were. The town with the greatest area and the total number of parcels was the town of Essex, while the one with the smallest was Starksboro. Williston, Winooski, Colchester, and Burlington all had similar total counts but different total areas. Burlington had only 124 more residential properties than Williston but Williston contained 670 more acres. This implies that some towns such as the town of Williston, had a larger average lot size., while others such as Burlington had much smaller lot sizes.

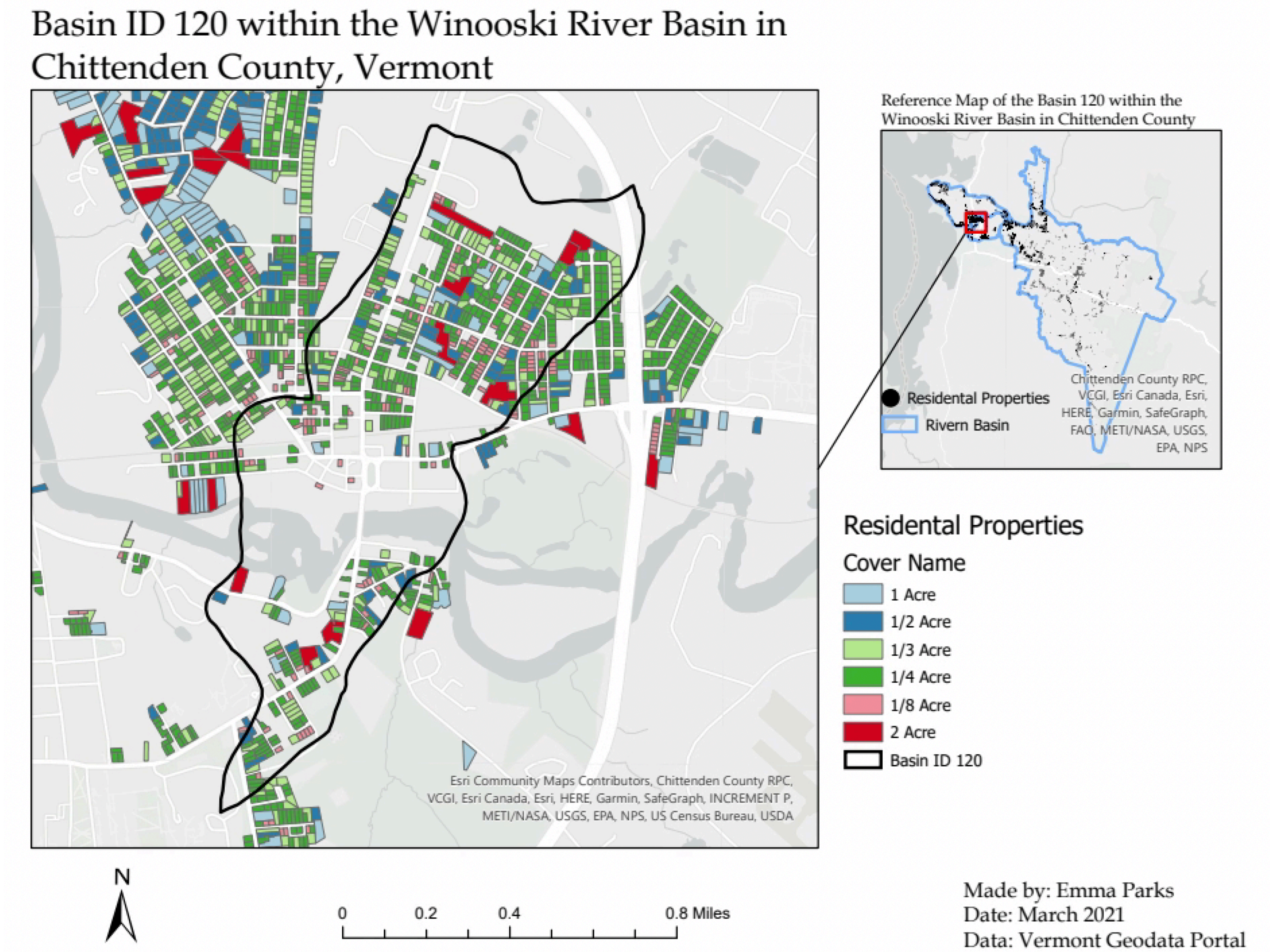
Soil Hydrology Group for the Winooski River Basin in Chittenden County, Vermont



Map 4.3: ArcMap showing the Soil Hydrologic Group distribution throughout the Winooski River Basin within Chittenden County Vermont.

Map 4.1 shows the Soil Hydrologic Group distribution for the Chittenden County portion of the Winooski River Basin. Hydrologic Soil Groups A and B are heavily concentrated in the Northwest portion of the basin, nearer to Lake Champlain. This is due to the sandy and loamy soils that are found closer to water sources. As one moves southeast the Hydrologic Soil Groups change to a higher concentration of C and D soils. These soils are farther away from Lake Champlain and are closer to the Green Mountains.

Map 4.2: ArcMap showing the residential properties lot size distribution within Sub Basin 120. This subbasin is located within the Winooski River Basin in Chittenden County, Vermont



Map 4.2 shows a close look at Basin 120 in the Chittenden County portion of the greater Winooski Basin. The black outline shows the boundaries of the basin, and the polygons show the residential lots used in this study.

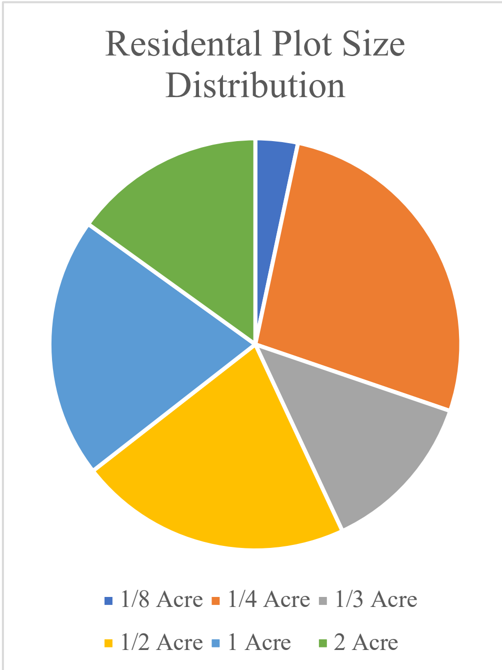


Figure 4.6: Pie Chart showing the distribution of residential plot sizes based on cover names for plots found in the Winooski River Basin within Chittenden County.

The residential lot size distribution for the Winooski River Basin within Chittenden County is shown in Figure 4.1. Plots that are less than ½ acre in size make up about 40% of the residential plots considered in this study. Another 40% are greater than 1/3 but less than 2 acres in size. About 20% are greater than 2 acres but less than 3 acres.

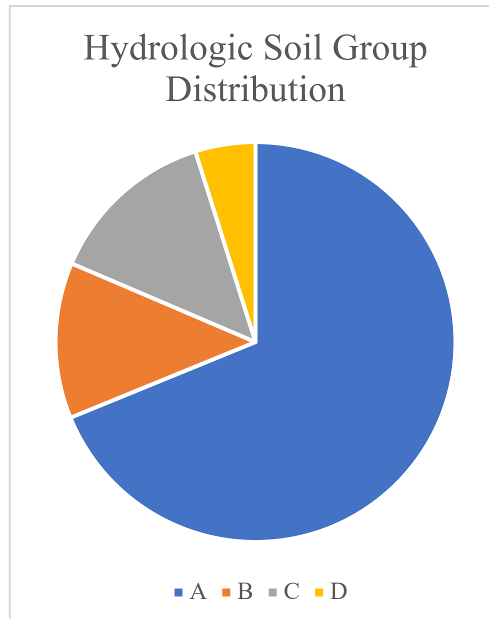


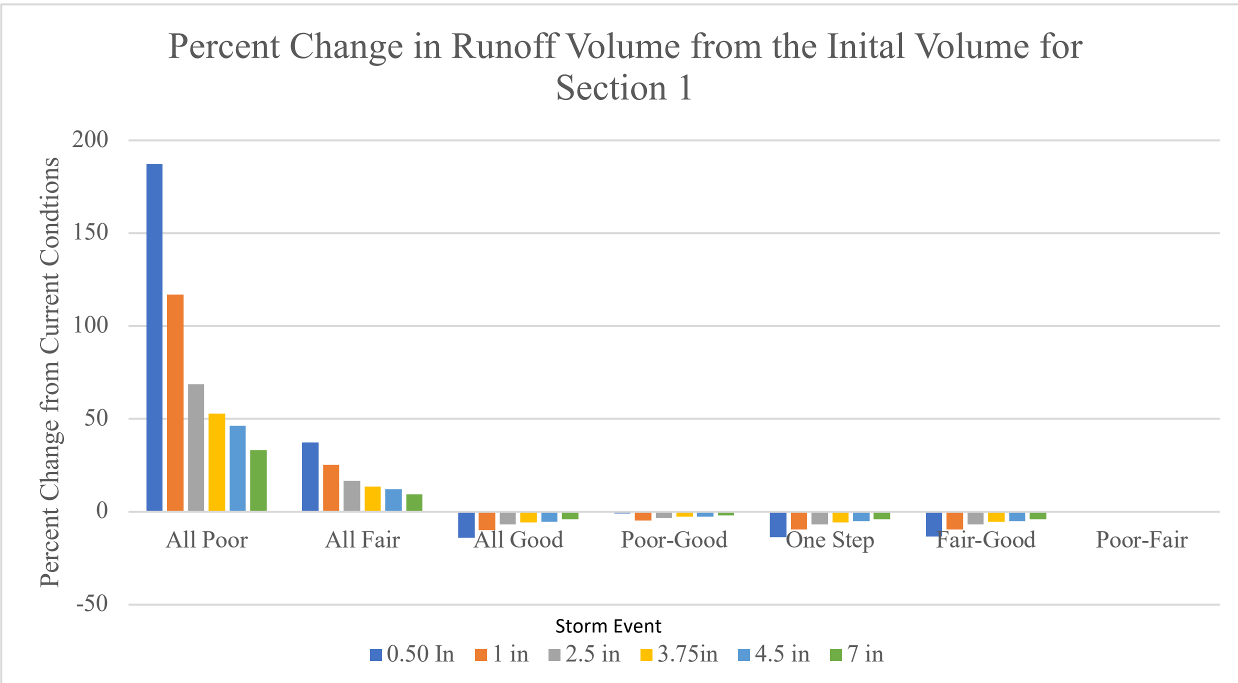
Figure 4.7: Pie chart showing the distribution of soil hydrologic conditions. Each residential plot sits on a certain hydrologic soil group so the distribution for the Winooski River Basin within Chittenden County is shown here.

The Soil Hydrologic Group, HSG, distribution for the Winooski River Basin in Chittenden County is shown in Figure 4.2. Approximately 60% of soils in the study area are HSG A. HSG A are known to have excellent infiltration properties. Approximately 20% are groups C and D which tend to be high in runoff generation with little infiltration (Figure 4.2).

Section 1: "All in" and "Interval" Changes

The Materials and Methods section describes seven scenarios under the heading Section 1. These scenarios were evaluated for the entire portion of the watershed in Chittenden County. They differed in lawn conditions and how the lawn conditions were modified. Figure B1 in the Appendix shows the lawn initial mean curve number, (CN_m) and the CN_m of lawns after they were changed. When changing current lawn conditions to all "Poor" the CN_m increased by ~24%. When changing the current lawn conditions to all "Fair", the CN_m increased by ~7%. Only when current lawn conditions were changed to all good, was there a decrease in CN_m (negative % change). When changing the current lawn conditions to all "Good" the CN_m decreased by ~3%. The final four scenarios did not change all the lawns but only specific lots. All four of these scenarios saw a decrease in CN_m. When all the lawns with the initial lawn condition of "Poor" were changed to "Good", leaving the "Fair" and "Good" lawns unchanged, the CN_m decreased by 1.5%. When all the lawns with current conditions of "Poor" were changed to "Fair" and all the current "Fair" lawns turned to "Good", then there was a decrease in CN_m of ~3%. When changing the lawns with the current condition of "Fair" to "Good" while leaving all other lawns alone, there was a decrease in CN_m of ~3%. Finally, when changing the current lawns with "Poor" conditions to "Fair", there was a decrease of just 0.05%.

Figure 4.8:Bar plot showing the percent change in total runoff volume for each storm event possibility (0.5 in, 1 in, 2.5in, 3.75in, 4.5in, and 7in) for each of the seven possible scenarios of section 1. The initial runoff volume is the total volume calculated for the current lawn conditions. These bars show the percent change from the initial volume for each scenario under different storm conditions

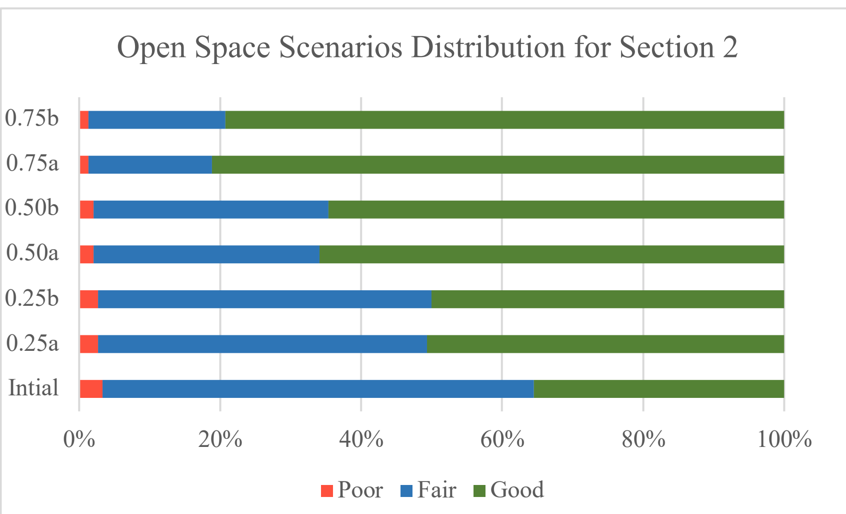


How do the curve number changes affect total runoff from the plot sizes considered? Figure 4.3 shows the total runoff volume for the seven scenarios for the six different storm events I chose to model. Two trends can be seen in these data. For the smaller storm events, there is a greater percent change in total runoff volume across all scenarios. This implies that the change in lawn condition has a greater impact during small storm events (impact either positive or negative) than it does in larger storm events. The other trend observed is that changing the lawn conditions to all "Poor" and "Fair" gives large increases in runoff over current conditions. In all other scenarios, the changes are very small. "All Good" and "Poor-Good" had the largest negative change or decrease in curve number. Scenario 7, or "Poor to Fair" had the smallest percent change in runoff volume with a decrease in runoff volume of 0.5%.

Section 2: Changing Open Space Conditions for a Certain Percentage of Lawns

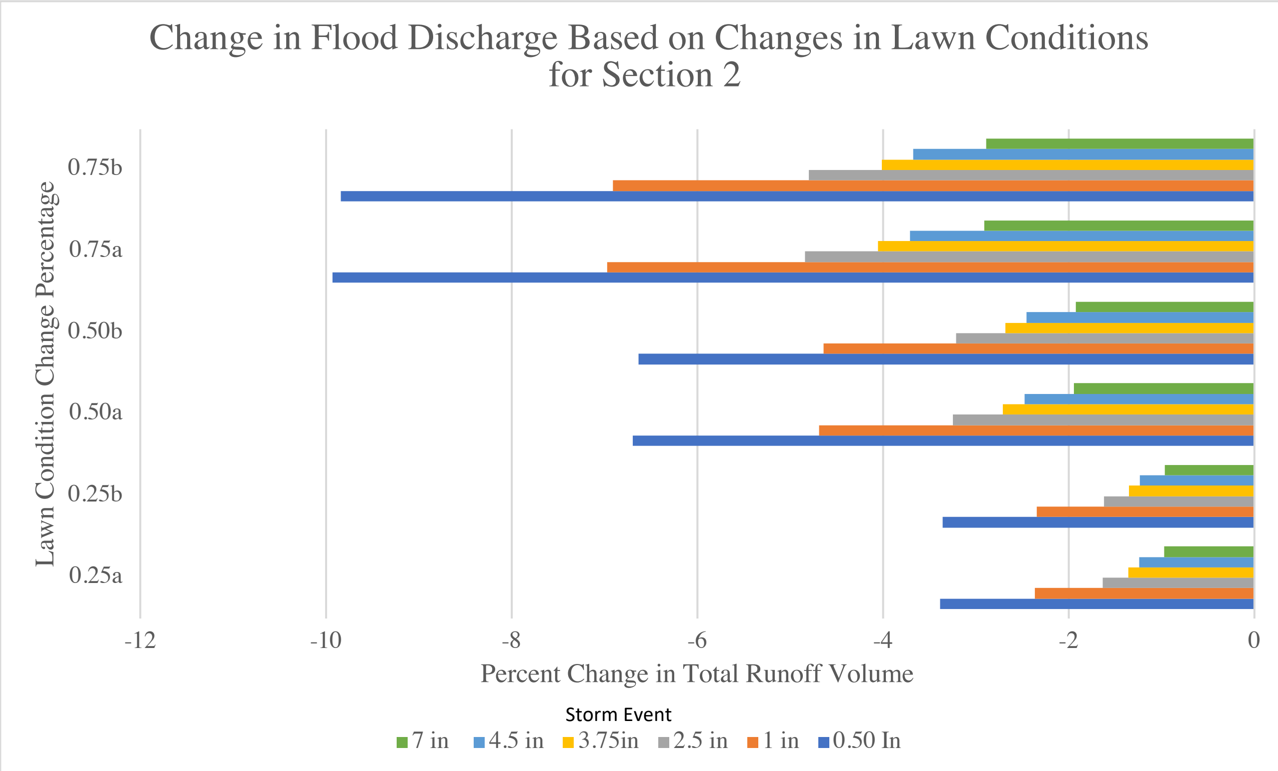
When considering changing only a fraction of the lawns, in this case, 25%, 50%, and 75%, from one condition to another, the average CN seems less sensitive to change. As a higher percentage of lawns are changed from a lesser quality of lawn to a better quality of lawn, average curve numbers decrease with the percentage of the lawns improved (Appendix B), but the changes are relatively small varying from 0.73 to 2.19 %. For each of the three fractional change scenarios, there are two sub- scenarios: Scenario A simulates the change from “Fair” or “Poor” conditions to “Good”, Scenario B simulates changes from lawns with the initial condition of “Poor” to “Fair” and initial lawn conditions of “Fair” to “Good” condition. The CN for Scenario A is just a fraction smaller than for scenario B. Figure 4.4 shows why the difference in CN is so small. The distributions of lawn conditions do not differ much between A and B within a change class (25%, 50%, and 75%).

Figure 4.9: Percent bar graph showing the distribution of the Open Space Condition for the residential lawn parcels for each scenario in Section 2. On the y axis the number represents the percent distribution i.e.,0 .25 = 25% change and the letter, ‘a’ or ‘b’ represent the two parts of each of the three scenarios



However, Figure 4.4 also shows that the improvement from the initial lawn condition for 25%, 50%, and 75% of the parcels improved lawn conditions as one would expect. The initial bar shows the distribution of established lawn conditions in the Winooski River Basin in Chittenden County. Nearly 60% of the initial lawn conditions were labeled “Fair” and approximately 35% were labeled “Good”. Less than 5% were labeled “Poor”. As the lawn conditions begin to change the percent of lawns labeled “Poor” and “Fair” decrease and lawns labeled “Good” increase. Figure 4.4 clearly shows that the algorithm used to change lawn conditions was effective. The outcome was that the change in lawn distribution with the “Good” condition increases at the expense of the “Fair” and “Poor”.

Figure 4.10: Bar plot showing the percent change in total runoff volume for each storm event possibility (0.5 in, 1 in, 2.5in, 3.75in, 4.5in, and 7in) for each of the three scenarios and their two parts for Section 2 of the lawn condition changes. The is the initial runoff volume is the total volume calculated for the current lawn conditions. These bars show the percent change from the initial for each scenario given different storms. Each collection of bars is the percent change in total runoff volume for each of the storm events for each part of the three scenarios. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, ‘a’ or ‘b’ represent the two parts of each scenario



The greater number of lawns improved the greater percent change in total runoff volume. The more lawns condition that was improved the greater the decrease in total runoff volume. Across all the conditions, the smaller the storm event the greater the percent change in total surface runoff. When looking at the 0.50 in. storm, for the 25% change (0.25a and 0.25b) the percent change in total runoff volume is approximately -3.5%. For the same storm event considering a 75% change of lawn conditions (0.75a and 0.75b), there is a decrease of total runoff volume of nearly 10%. Although the smaller storms had a larger percent change, the total volume of the impact was much less than that of the larger storms. When looking at the 25% change (0.25a) during a 0.50 in. storm there is a difference in total runoff volume of 4.684 acre-inches and a percent decrease of 3.39%. Considering that same condition (0.25a) during the 7 in. storm there is a difference in total runoff volume of 226.06 acre-inches representing a reduction in runoff volume of 0.97%. Large storms generally have more runoff than smaller storms, so though changing the lawn condition has some effect, it is not as significant when looking at the entire watershed.

Section 2.1: Comparing the Changes based on Lot Size

Table 4.6: Table showing mean curve number (CN_m) change from scenarios in Section 2 categorized by lot size. The total area for each cover name category is also shown. The heading number represents the percent change i.e.,0 .25 = 25% change, and the letter, 'a' or 'b' represents the two parts of each scenario

Lot Size Condition Change							
	Initial	0.25a	0.25b	0.50a	0.50b	0.75a	0.75b
1/8 Acre							
CN_m	**87.727**	**85.927**	**86.558**	**83.942**	**85.264**	**81.895**	**83.929**
1/4 Acre							
CN_m	**69.091**	**67.720**	**67.720**	**66.286**	**66.286**	**64.890**	**64.890**
1/3 Acre							
CN_m	**68.198**	**66.695**	**66.695**	**65.136**	**65.136**	**63.662**	**63.662**
1/2 Acre							
CN_m	**68.924**	**67.345**	**67.345**	**65.830**	**65.830**	**64.244**	**64.244**
1 Acre							
CN_m	**60.653**	**60.653**	**60.653**	**60.653**	**60.653**	**60.653**	**60.653**
2 Acre							
CN_m	**63.972**	**63.972**	**63.972**	**63.972**	**63.972**	**63.972**	**63.972**

Table 4.4 shows curve number changes with the lawn approvements in 25, 50, and 75% of the lawns. 1-acre plots and 2-acre plots have the same initial value because with this methodology residential plots 1 acre or larger will always have a default "Good" open space condition based on the average percent impervious. Thus, when separating the 1 acre and 2-acre plots from the others there is no change in the mean curve number, CN_m, because there is no change to the open space condition, in this basin scenario (Table 4.4). The common trend for plots 1/8-1/2 acre is that the CN_m decreases as the percent lawns changed increases. 1/3-acre plots saw the greatest difference from the initial CN to the 75% change in lawn conditions, a value of ~5.

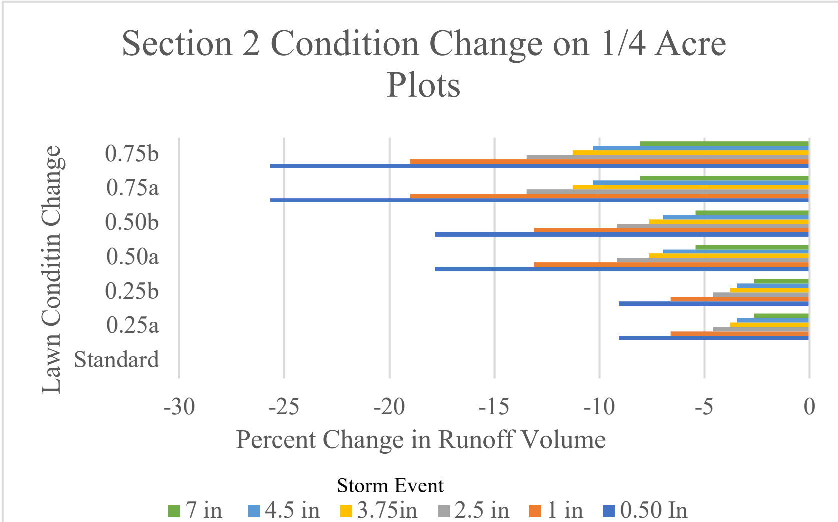


Figure 4.6: Bar plot showing the percent change in total runoff volume for residential plots with cover name "1/4 Acre". These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

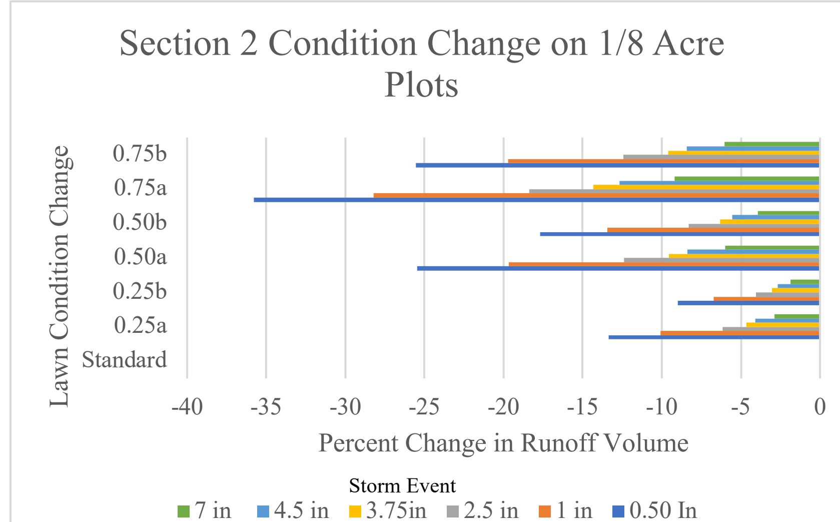


Figure 4.7: Bar plot showing the percent change in total runoff volume for residential plots with cover name "1/8 Acre". These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

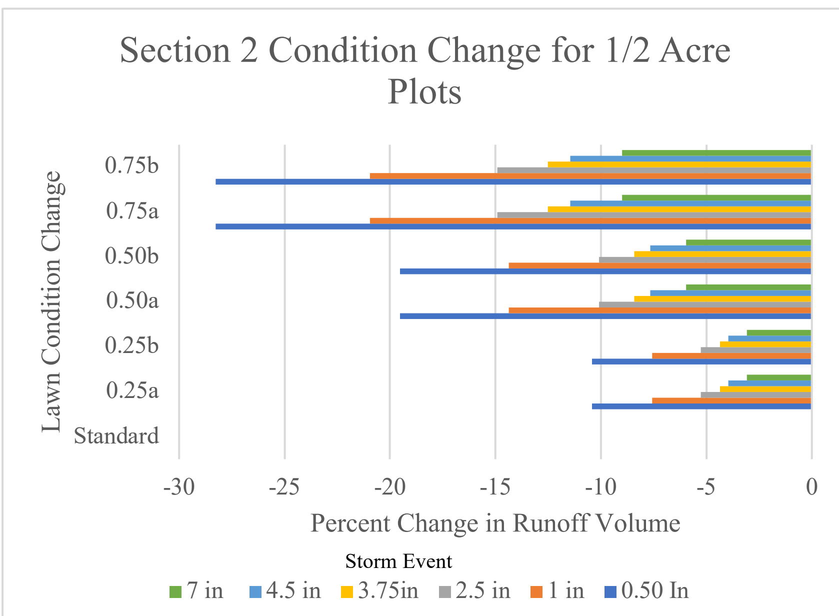


Figure 4.8: Bar plot showing the percent change in total runoff volume for residential plots with cover name "1/2 Acre". These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

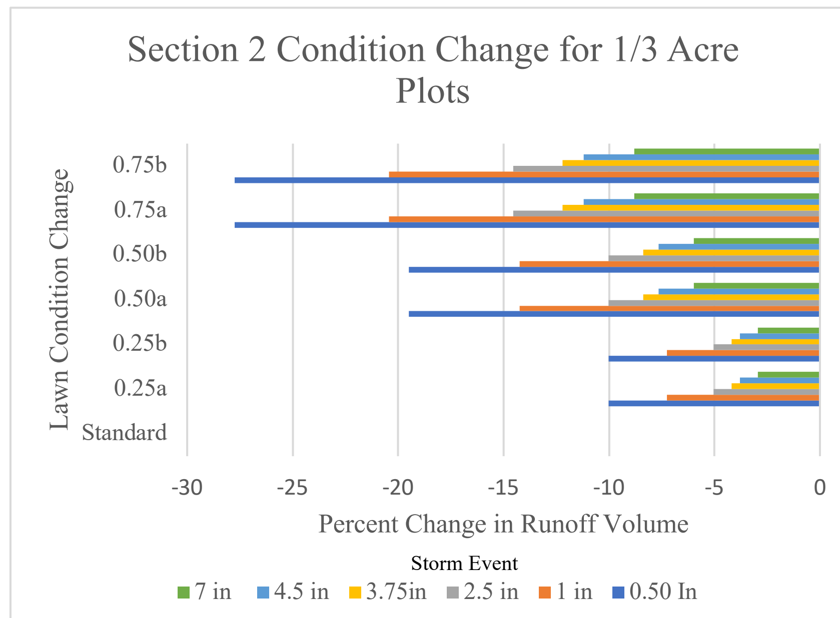


Figure 4.9: Bar plot showing the percent change in total runoff volume for residential plots with cover name "1/3 Acre". These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

In the scenarios where lawns were improved by 25, 50, and 75 % of plots there were two distinct trends within the data. The first relates to lot size and the second relates to storm size. The smaller the lot greater the percent change in runoff volume. The smaller the storm the larger the percent change in total runoff volume.

Figures 4.5-9 represent the decrease in total runoff volume of the three change scenarios (25% change, 50% change, 75% change) from the initial. As expected, the greater number of lawns changed the greater the percent change in total runoff volume. The more lawns that were improved the greater the decrease in total runoff volume across all plot sizes. Throughout all the conditions, the smaller the storm event the greater the percent change in total surface runoff. Additionally, the smaller the plot the larger the percent change in total runoff volume. The 1/8 plots had the highest percent change, though there was also the least number of houses classified as 1/8-acre plots (Figure 4.1) so they contributed the smallest total area. The larger the lot the greater the difference in total volume runoff. For 1/8-acre plots during a 0.50 in storm with the condition 0.25a, the difference in total runoff volume was only 0.62-acre inches. When looking at this same plot and condition (0.25a) for a 7 in. storm the difference in volume is only 6.67-acre inches. When looking at ½ acre plots for this same condition (0.25a) during a 0.5-inch storm the percent decrease of 0.4% and the difference in total volume is 2.927-acre inches. For a 7 in. storm the percent change decreased by 3.01% but the difference in runoff volume is 117.17 acre-inches. ½ Acre and 1/3 Acre had nearly the same percent changes although ½ Acre plots still had a higher percentage change through the conditions.

Section 2.2: Comparing Changes based on Soil Hydraulic Group

In Section 2.1 the percent lawn condition changes were compared based on their lot sizes. This Section compared the percent lawn condition changes based on their Hydrologic Soil Group.

Table 4.7: Table showing mean curve number (CN_m) change from scenarios in Section 2 categorized by Soil Hydrologic Group. The total area for each Soil Hydrologic Group is also shown. The heading number represents the percent change i.e.,0 .25 = 25% change, and the letter, 'a' or 'b' represents the two parts of each scenario

Soil Hydrologic Group Condition Change							
	Initial	**0.25a**	**0.25b**	**0.50a**	**0.50b**	**0.75a**	**0.75b**
A Soil							
CN_m	**55.4524963**	**54.7328033**	**54.7400264**	**54.0100299**	**54.0254731**	**53.2942581**	**53.3181378**
B Soil							
CN_m	**68.2862651**	**68.0360406**	**68.0377893**	**67.7617527**	**67.7644337**	**67.4757812**	**67.4795963**
C Soil							
CN_m	**78.6608525**	**78.4899921**	**78.4899921**	**78.3380222**	**78.3380222**	**78.1686921**	**78.1686921**
D Soil							
CN_m	**83.1506578**	**83.0584647**	**83.0584647**	**82.9814756**	**82.9814756**	**82.8975404**	**82.8975404**

As the percent lawn changed increases the curve numbers decrease. The largest decrease in curve numbers is found with HSG A. With an initial value of ~55, the CN_m decreases to ~53 when 75% of lawn conditions are changed. HSG C and D have the smallest change in CN_m of ~1.

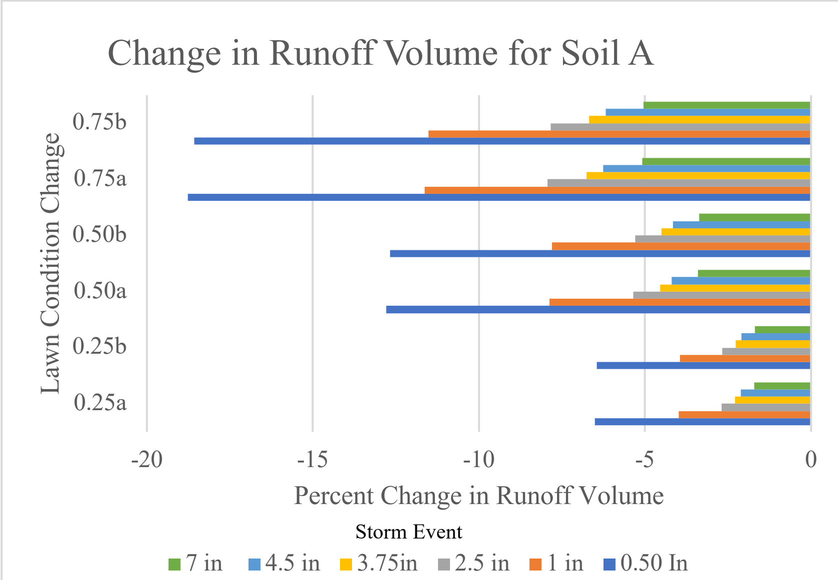


Figure 4.10: Bar plot showing the percent change in total runoff volume for residential plots with Hydrologic Soil Group A. These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

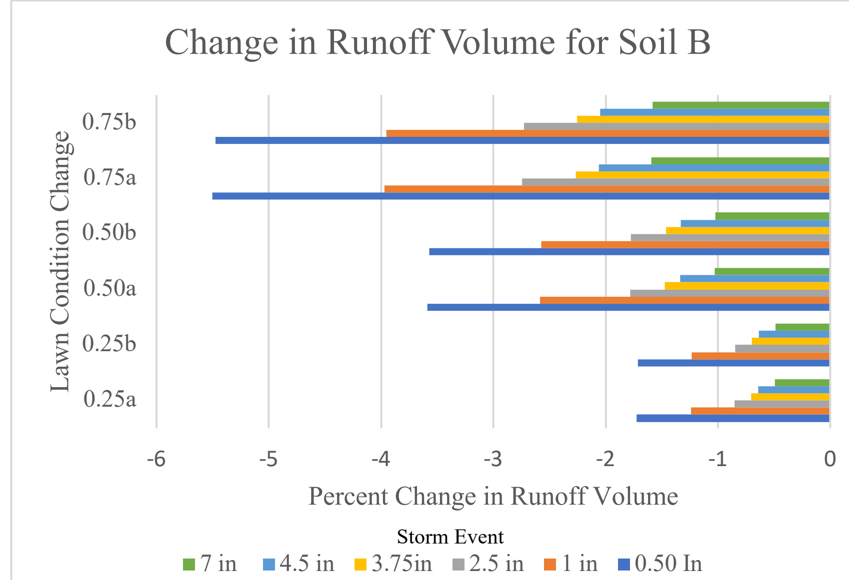


Figure 4.11: Bar plot showing the percent change in total runoff volume for residential plots with Hydrologic Soil Group B. These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

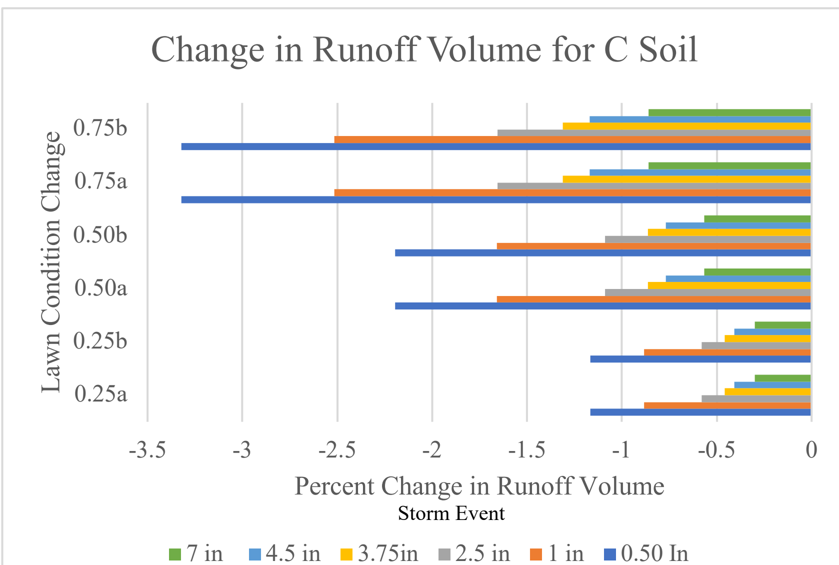


Figure 4.12: Bar plot showing the percent change in total runoff volume for residential plots with Hydrologic Soil Group C. These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

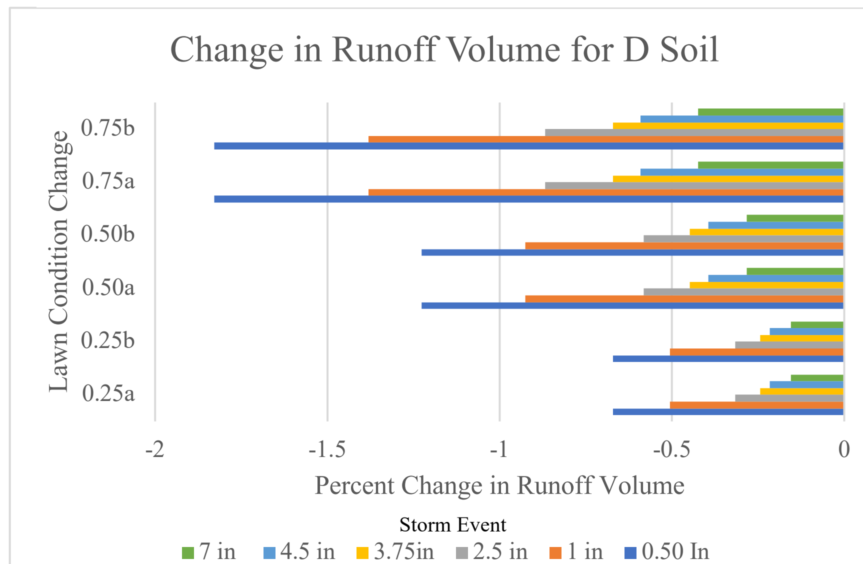


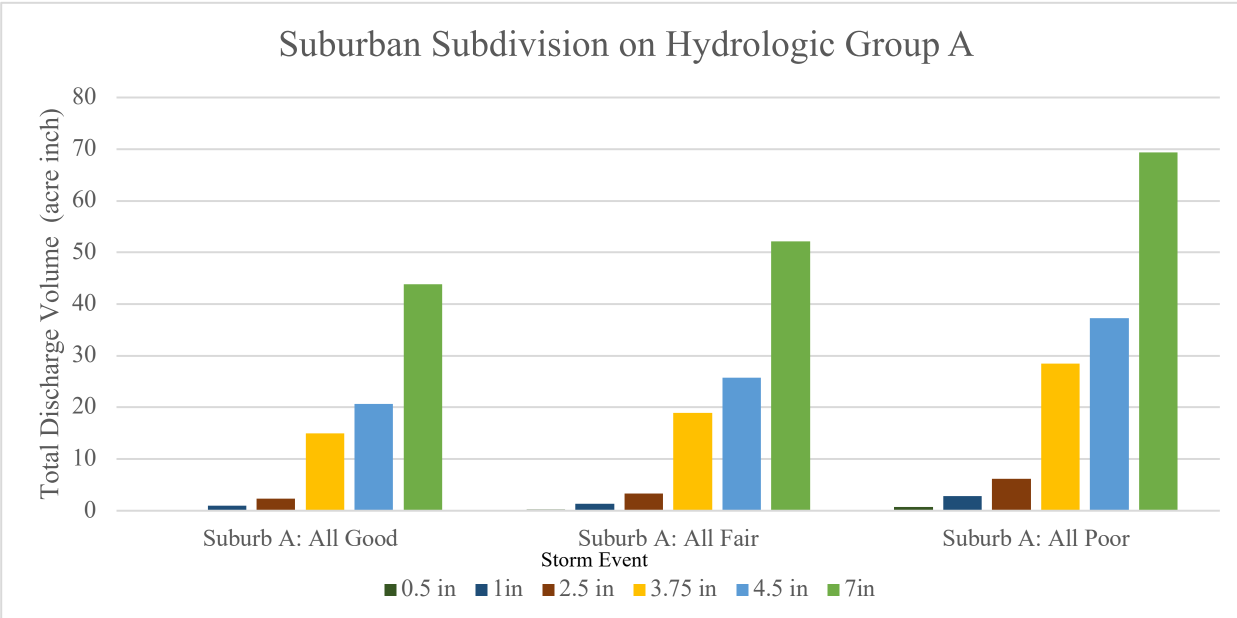
Figure 4.13: Bar plot showing the percent change in total runoff volume for residential plots with Hydrologic Soil Group D. These bars show the percent change from the initial for each scenario given different storms. Each bar represents the percent change from the initial runoff value. The negative percentages represent the decrease in total runoff volume of the conditions) from the initial. Each subset of bars is the percent change in total runoff volume for each of the three scenarios given the different storm events. On the y axis the number represents the percent change i.e.,0 .25 = 25% change and the letter, 'a' or 'b' represent the two parts of each scenario

Figures 4.10-13 represent the decrease in total runoff volume of the three scenarios (25% change, 50% change, 75% change) from the initial for three Soil Hydrologic Groups, HSG. I used the same data as considered in Section 2.1 but analyzed based on the hydrologic group. The same outcomes are observed when comparing changes due to the number of lawns that were changed and for the different storm sizes. However, when comparing outcomes between hydrologic groups, HSG A had the greatest percent changes while HSG D had the least change in total runoff volume. As shown in Figure 4.2, HSG A was the most abundant HSG with the largest total area. HSG D had the smallest area (Table 4.5). HSG A and HSG B have the largest percentage change and total runoff value when lawn conditions were changed. Evaluating HSG A during a 0.5 in storm for condition 0.25a the difference in total runoff from the initial is 2.26-acre inches while for a 7in. storm the difference is 171.99-acre inches. By comparison, when the HSG was D, then the difference in a 0.5in. storm is 0.275-acre inches and for a 7in. storm it is 4.17-acre inches. In all, there was nearly 10 times less change for HSG C and D than there was for A and B.

Section 3.1: Theoretical Development Conditions

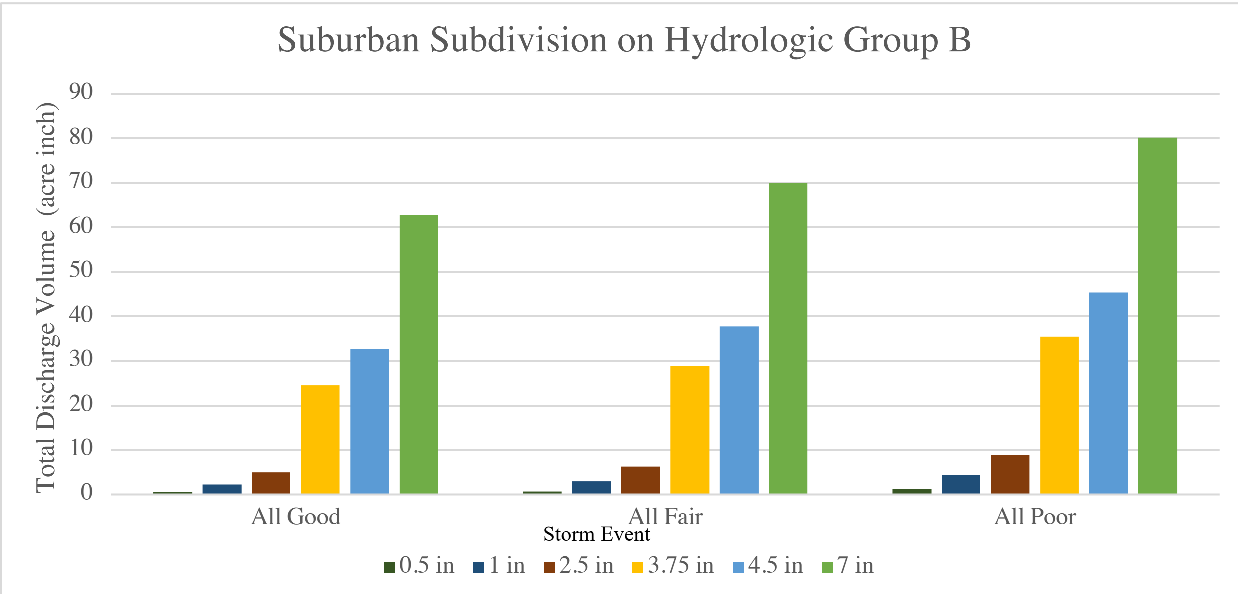
In the previous section runoff volume that occurred in the entire watershed was analyzed. The changes that occurred with changes in lawn condition were modest and likely would not have much impact on total discharge to the Winooski River. However, investigating the potential outcomes at a different scale, for example, individual house lots or subdivisions, the results may be different. While there may not be much of an impact on the Winooski River, a more localized impact may be observable that could impact the design of stormwater infrastructure. In this section, the smaller scale was investigated by creating two theoretical subdivisions each with 30 houses on ½ acre plots one with Hydrologic Soil Group A and one with Hydrologic Soil Group B.

Figure 4.14: Bar chart showing the total discharge volume (acre-inch) from each of the storm event possibility (0.5 in, 1 in, 2.5in, 3.75in, 4.5in, and 7in) for the three Open Space conditions of the theoretical suburban subdivision on hydrologic group A. The subdivision consists of 30 homes on ½ acre lots. Three possible lawn quality conditions are indicated: "Good", "Fair", or "Poor".



As the total lawn conditions worsen from "Good" to "Poor" the total runoff volume increase across all storm events (Figure 4.14). When all the lawn conditions are "Good" there is a total runoff during a 3.75in storm of ~15 acre-inches. If all the lawns were changed to a "Poor" condition, then the total runoff volume nearly doubles to ~30 acre-inches. This trend continues across all storms. The better the lawn quality the less total runoff volume.

Figure 4.15: Bar chart showing the total discharge volume (acre-inch) from each of the storm event possibility (0.5 in, 1 in, 2.5in, 3.75in, 4.5in, and 7in) for the three Open Space conditions of the theoretical suburban subdivision on hydrologic group B. The subdivision consists of 30 homes on ½ acre lots. Three possible lawn quality conditions are indicated: "Good", "Fair", or "Poor".



As the total lawn conditions worsen from "Good" to "Poor" the total runoff volume increase across all storm events. When all the lawn conditions are "Good" there is a total runoff during a 3.75in storm of ~22 acre-inches. If all the lawns were changed to a "Poor" condition, then the total runoff volume increases to ~35 acre-inches. This trend continues across all storms. The better the lawn quality the less total runoff volume.

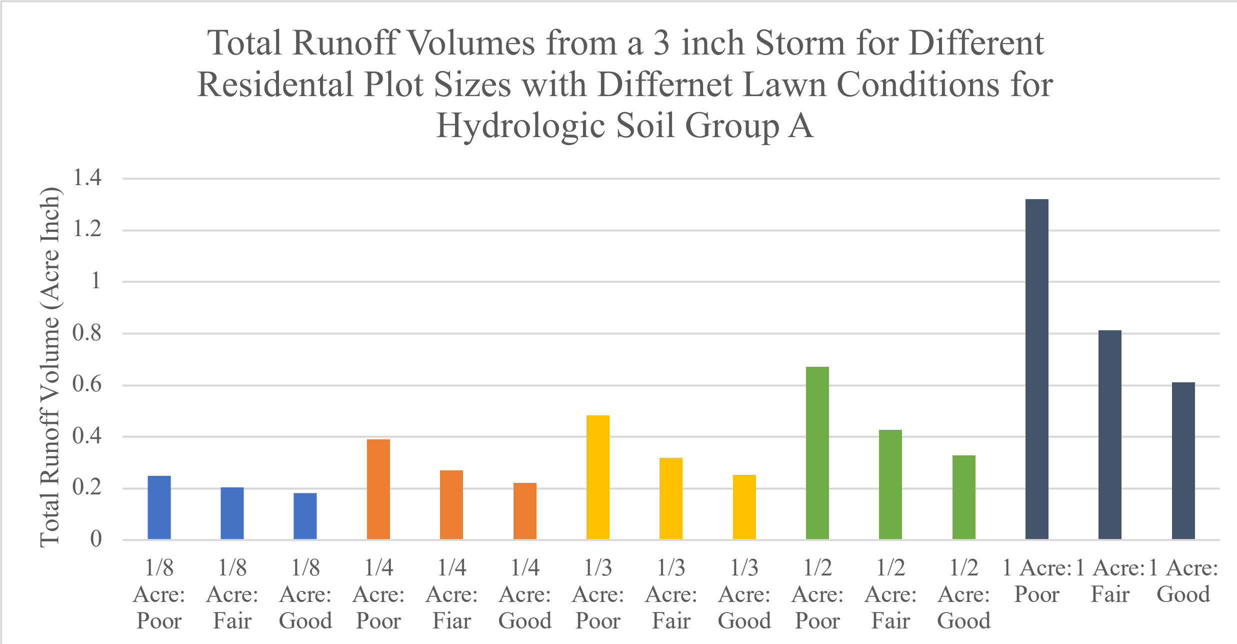
Section 3.2: Theoretical Housing Plot Conditions

Table 4.8: Table showing the percent change in CN_m with a change in lawn condition for five different potential lot sizes. Each lot size is considered theoretically on a different hydrologic soil group. Then within each soil group, there is an open space condition change for the lawns and then the subsequent curve number percent change. The percentages show the decrease in the composite curve number when changing the open space condition for the plots.

	1/8 Acre	**¼ Acre**	**1/3 Acre**	**½ Acre**	**1 Acre**
Soil A					
Poor-Good	-11.60%	-22.64%	-26.36%	-29.19%	-31.35%
Poor-Fair	-7.60%	-14.84%	-17.27%	-19.12%	-20.54%
Fair-Good	-4.33%	-9.17%	-10.99%	-12.44%	-13.61%
Soil B					
Poor-Good	-6.90%	-12.94%	-14.88%	-16.31%	-17.39%
Poor-Fair	-3.83%	-7.19%	-8.26%	-9.06%	-9.66%
Fair-Good	-3.19%	-6.20%	-7.21%	-7.97%	-8.56%
Soil C					
Poor-Good	-4.48%	-8.22%	-9.37%	-10.22%	-10.86%
Poor-Fair	-1.85%	-3.35%	-3.82%	-4.15%	-4.41%
Fair-Good	-1.92%	-3.60%	-4.13%	-4.53%	-4.83%
Soil D					
Poor-Good	-3.32%	-6.04%	-6.87%	-7.48%	-7.93%
Poor-Fair	-1.85%	-3.35%	-3.82%	-4.15%	-4.41%
Fair-Good	-1.50%	-2.78%	-3.17%	-3.47%	-3.69%

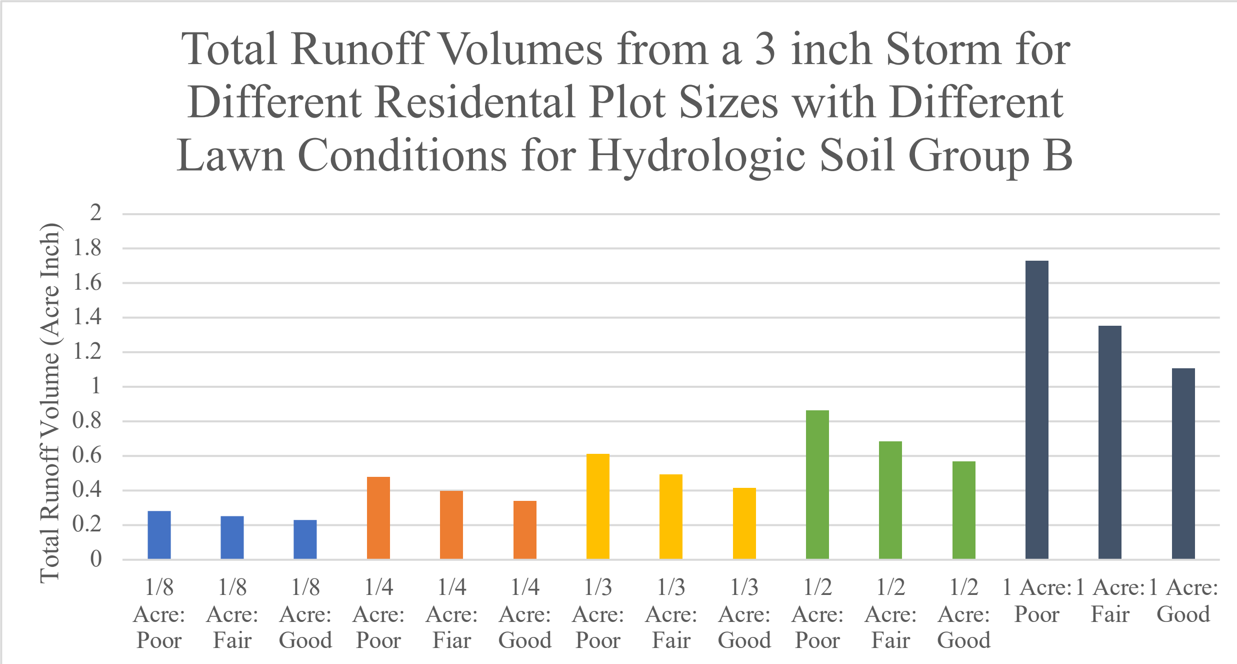
Across all Hydrologic Soil Groups (HSG) as the house lot size increases the percent difference in CN_m is greater. The greatest change in CN_m is found for HSG A with a CN_m percent decrease of 11.5% for 1/8-acre plots to 31.35% for the 1-acre plots. The smallest change in CN_m is found on HSG D with a CN_m percent decrease of 3.32 for 1/8-acre plots to 7.93% for 1-acre plots. For each HSG changing the lawn conditions from "Poor" to "Good" had the greatest change in CN_m while the lawn condition change of "Fair" to "Good" had the smallest. This shows that improving lawn conditions from "Poor" to either "Fair" or "Good" has a larger impact than improving "Fair" condition lawns to "Good".

Figure 4.16: Bar chart showing the total discharge volume (acre-inch) from a storm event of 3 in for the three Open Space conditions of the theoretical housing lot sizes on hydrologic group A. Five lots of different sizes; 1/8, ¼, 1/3, 1/2 and 1 acre. Three possible lawn quality conditions are indicated: "Good", "Fair", or "Poor".



As shown in Figure 4.16 across all lot sizes as the lawn condition changes from "Poor" to "Good" the total runoff volume decreases. The larger the lot size the greater total runoff and the greater difference in runoff volume from the lawn condition change. When the lawn conditions of a 1/8 acre plot are "Poor" there is about ~0.2-acre inches of runoff, if the lawn condition is "Good" there is a runoff volume of less than 0.2-acre inches. If the lot size is 1 acre there is a greater difference in total runoff volume, with "Poor" lawns total runoff being ~1.3-acre inches and "Good" lawns total runoff being ~0.6-acre inches.

Figure 4.17: Bar chart showing the total discharge volume (acre-inch) from a storm event of 3 in for the three Open Space conditions of the theoretical housing lot sizes on hydrologic group B. Five lots of different sizes; 1/8, ¼, 1/3, 1/2 and 1 acre. Three possible lawn quality conditions are indicated: "Good", "Fair", or "Poor".



In comparison to Figure 4.16, residential lots on Hydrologic Soil Group B (Figure 4.17) have an increased total runoff volume across all lot sizes and lawn conditions. As shown in Figure 4.17 across all lot sizes, as the lawn condition changes from "Poor" to "Good" the total runoff volume decreases. The larger the lot size the greater total runoff and the greater difference in runoff volume from the lawn condition change. When the lawn conditions of a 1/8 acre plot are "Poor" there is about ~0.3 acre-inches of runoff, if the lawn condition is "Good" there are ~0.2-acre inches of runoff volume. If the lot size is 1 acre there is a greater difference in total runoff volume, with "Poor" lawns total runoff being ~1.5-acre inches and "Good" lawns total runoff being ~1.1 acre-inches. Hydrologic Soil Group A (Figure 4.16) supports a greater difference in total runoff volume as the lawn conditions change than Hydrologic Soil Group B (Figure 4.17).

V. Discussion

A pillar of suburban American life, lawns are a distinguishing feature in urban developments. Made popular in the 1800s by the Victorians, lawns are a trend that seems to be unchanging in American society. Though lawns may be a permanent fixture in our society, our perception and utilization of lawns are becoming more malleable. How Americans view lawns is changing as more studies show the harm in monoculture turf-style lawns. Detrimental to ecological diversity and a major contributor to pollution runoff, lawns are more dangerous than they appear. As recurrence intervals decrease for major storm events, stormwater mitigation and infrastructure come to the forefront of urban planning schemes. As more homes, subdivisions, and cities are constructed, the impervious surface area increases. The combination of stormwater and less pervious surfaces equates to an increase in flooding probability. However, residential lawns hold a solution for local stormwater management. Lawns are areas already dedicated to open space. The quality of these open spaces has an impact on the total runoff during storm events. Compared to poorly maintained lawns, well-maintained lawns reduce the total runoff volume during storm events by improving the infiltration rates.

In this thesis, I investigated whether improving lawn quality reduced the total runoff volume using the Curve Number method. I started by analyzing the lawns located in the Chittenden County portion of the Winooski River Basin in Northwestern Vermont. In Sections 1 and 2 the changes in curve number and total runoff volume associated with altering lawn qualities were simulated. Section 3 considered theoretical scenarios, focusing on smaller-scale lawn changes in subdivisions and individual housing plots. Understanding the correlation between lawn quality and the total runoff volume allows for stormwater infrastructure design to be more targeted to the drainage area, thus being more ecologically and economically efficient.

Lawn Change at a Large Scale

Residential lawns make up only a small portion of any given watershed. This means that though they affect water infiltration, pollutant runoff, ecological habitat, and abundance, etc., the total impact is small when looking at an entire basin. For this large-scale look at the impact on residential lawns, I evaluated 10,569 residences located within the Chittenden County portion of the Winooski River Basin. These are only a portion of the total residences because the study sample was limited to residential plots that were ⅛ acre to 3 acres in size. Sections 1 and 2 of this study focus on these residential plots and how their total runoff volume contributes to the watershed. Figures 4.3 and 4.5 show the percentage change in runoff volume for these residential parcels when their lawn conditions are changed. Figure 4.5 shows that improving the lawn conditions has the greatest impact in smaller-scaled storms (0.5in-2.5in). For larger storm events there is still a reduction in total runoff value although the changes in volume are smaller. Though improving the lawn conditions reduces the total runoff volume, the change when considering the entire watershed is small. Table 4.3 shows that even by improving the quality of 75% of the lawns the mean curve number reduces only by ~2%. This slight reduction in curve number translates to a definite but small change when looking at the total runoff volume.

To have a better understanding of these lawn changes when looking at such a large scale, two lawn qualities were compared: lot size and Hydrologic Soil Groups. Figures 4.6-9 show that the larger the lots have a greater potential contribution to runoff volume. However, these figures also show that smaller lots have the greatest potential for change, indicated by the highest percent change in total runoff volume coming from ⅛ acre and ¼ acre plots (Tables 4.6 and 4.7). Table 4.5 shows the effect that the Hydrologic Soil Group, HSG, has on the total runoff. Since HSG A is characterized by its high levels of absorbance and infiltration rates, residential plots located on these soils saw a more significant decrease in curve number and total runoff volume across all condition changes. HSG C and D had the smallest change in curve number (Table 4.5) and the smallest percent change in total runoff volume (Figures 4.10-13). Having these two comparisons, lot size and HSG, allow us to see those smaller residential plots on HSG A or B have the greatest potential to lower their total runoff volume. When looking at the entire basin these smaller decreases in runoff volume have little effect on the total discharge of the Winooski River. However, lawns are some of the largest contributors of nutrient loading into Lake Champlain so any reduction in runoff volume has a greater impact on the amount of nutrient loading (LCBP,2020).

Lawn Change at a Local Scale

If changing lawn conditions does not have a large impact on the total runoff within the river basin, can it be seen to influence a more local level? As the number of subdivisions in the United States increase, the average lot area decreases. In 2019 the average new-build lot size decreased to 0.25 acres from almost 1 acre (Cornish, 2019). The development of subdivisions leads to soil compaction, erosion, and increased impervious surfaces (Qin, 2020). To reduce the amount of flooding and runoff, subdivision designs usually include retention basins to capture and store the runoff from storm events. The construction of these retention basins can be costly and reduce the load from the individual lots would lessen the required design capacity. To investigate whether changing the lawn quality of a subdivision affects the total runoff volume, two theoretical subdivision scenarios were created. Both subdivisions were calculated for 30 single-family homes on ½ acre lots, one was Hydrologic Soil Group A while the other was Hydrologic Soil Group B.

In conformation of the data found for Sections 1 and 2, as the lawn quality increased in the theoretical subdivisions the total runoff volume decreases for the theoretical data (Figure 4.14 and 4.15). The subdivision on HSG A had a greater change in the total runoff volume than HSG B, though the subdivision on HSG B had more runoff overall (Figures 4.14 and 4.15). These two figures show that the quality of lawn can have a significant impact on the total runoff volume during storm events. Therefore, the HSG of the residential lots is an important consideration in the design of retention pond dimensions and capacity. If subdivisions placed higher importance on the quality of lawns the improved conditions potentially reduce the size of required retention ponds. Poorly maintained lawns, with low absorbency and infiltration rates, lead to more runoff volume and subsequently larger more expensive retention ponds and stormwater infrastructure. If the quality of all the lawns in a subdivision has an impact on the total runoff volume, then the role of the individual residential plot also has an impact. When looking at individual houses the size of the lot and the Hydrologic Soil Group play critical roles. As shown in Figures 4.10-4.13, HSG A has the greatest decrease in total runoff volume when lawn conditions are changed. When analyzing theoretical housing lots, houses on HSG A and HSG B the greatest reduction in total curve number was demonstrated when lawns were changed from “Poor” to “Good” (Table 4.6). Table 4.6 indicates that for individual houses the larger the lot size the greater reduction in curve number. These findings contradict what was found for the Winooski River Basin in Figures (4.6-4.9). There are many possible reasons for this discrepancy, primarily that the river basin has an uneven distribution of lot sizes. The Winooski River basin predominantly consists of large plots, which when considered separately were shown to have a lesser impact on potential runoff volumes. It appears that the greater potential for improvement inherent in the smaller plots was overshadowed by the minimal contributions from the larger plots. For the theoretical plots in Appendix A, it was evident that when changing the lawn conditions from “Poor” to either “Fair” or “Good” there was a greater reduction in curve number than changing a “Fair” lawn to

“Good”. While a “Good” lawn condition is the most preferable, lawn conditions of “Fair” are still more desirable than “Poor”.

Stormwater infrastructure designs change in accordance with the size of the drainage area. For drainage areas less than 10 acres, rain gardens are the appropriate stormwater infrastructure. This means that the average American home could benefit from the introduction of a rain garden to their landscaping. Rain gardens are located at the interception of runoff from impervious or non-absorbent areas (USDA, n.d.). They are typically planted with perennial native species, in depression wells built to capture runoff and slowly release it back into the soil (Dunnett, 2007). Similarly, to stormwater retention design in subdivisions, the total runoff volume from an individual housing lot drives the size and design of rain gardens for individual residential properties.

Future of Lawns

As more information is known about the hazards of turf lawns, people are looking for alternative lawn management styles. Since one is not able to change the soil hydrologic grouping of their lawns, they can instead change the overall design of their lawn to improve lawn condition and decrease the relative curve number. The addition of rain gardens and retention ponds are mitigation techniques for runoff but that is not a change in the lawn condition. To improve the total grass cover and thus improve the lawn condition there are various methods; improvement of soil health, increase biodiversity, and change/manipulates the lawn grading. Ecologically focused lawns are often easier to maintain, supporters of biodiversity, and reducers of water, heat, and soil erosion (UMN, 2019). As one focuses on more ecologically diverse lawns their overall lawn quality increases thus reducing the lawn curve number. Such lawns are tailored to the needs of an individual, but the same general principles can be followed to help reduce total runoff volumes; use of native grasses and plant species, the incorporation of trees and shrubs, and the reduction of soil additives (fertilizers, pesticides, and herbicides). The structure of grasses gives them a good natural ability to intercept and hold back stormwater. The interception value of bluegrass species is estimated at around 50% (Corbett, 1986), other hard fescues and hybrid bermudagrasses require less watering and retain more water (Huang, n.d.). Planting trees and other woody species provides numerous additional benefits to lawns and lawn-owners. Planting trees has been found to improve human health through carbon sequestration and air quality improvements (Roy, 2012). Trees also provide stormwater attenuation, reduction of the heat island effect, and visual aesthetic benefits (Roy, 2012). The reduction of pesticide and fertilizer use is necessary for the protection of vulnerable waterways and aquatic ecosystems. There are numerous ways to reduce pesticide use by using integrated pest management, introducing natural predators, or changing the notion of what a weed or pest is (Barzman, 2015).

Citation

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VI. Conclusion

As the risk of urban flooding increases, stormwater management has a greater role in urban planning. The control of runoff is crucial to the health of the land and waterways as well as important for the safety and maintenance of the built environment. The purpose of this thesis was to investigate whether the quality of lawns within a certain area could affect the expected runoff volumes during storm events. The results of this study make it clear that the choices made at the scale of individual residential lawns can have a measurable impact on potential stormwater runoff volume. The design and maintenance of high-quality planted areas as part of urban and suburban fabric can impact the hydrology of the ecosystem. Though lawn condition quality may have a smaller impact on the greater Winooski River Basin, at the local scale, lawn quality has a substantial impact.

Appendices

Appendix A
- Full Data Set

Appendix B
- All In and Interval Raw data

Appendix C
- Percent Change Raw Data

Appendix D
- Percent Change Based on Lot Size Raw Data

Appendix E
- Percent Change Based on HSG Raw Data

Appendix F
- Theoretical Housing Scenario Raw Data

Appendix G
- Theoretical Subdivision Scenario Raw Data